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AMERICA'S AIR SERVICE.*

BY

W. F. DURAND, Ph.D.,

Chairman, National Advisory Committee for Aeronautics.

THE purpose developed in May and June last looking toward the development by the United States of a great air fleet as one of its chief contributions in the world war met with instantaneous response in the heart and in the imagination of the American people.

The bill which was prepared and which was intended to put into effect the first stage of this great program passed Congress by a well-nigh unanimous vote and almost without discussion. Probably never before in the history of Congressional legislation has a bill been accepted by the nation's law-makers with so little knowledge of the detailed estimates and precise measures contemplated. Certainly never before has any such sum ever been appropriated out of hand for a single agency of war.

The history of the development of the great movement thus authorized by Congress, in so far as it can now be properly made public, cannot fail to have some interest for the American people, and the following paper has been prepared for the purpose of rendering some partial account of the more intimate purposes of such a war measure and of the steps needful in their realization.

The possibilities of a great aerial fleet have, since the early

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days of the war, appealed vividly to hundreds of people, both within and without the military and naval services. It is, however, probably fair to say that it was not until the interchange of information and of views made possible by the visits of the Balfour and Viviani-Joffre commissions to Washington in May that the possibilities inherent in the operation of such a fleet, together with the possibilities of its actual realization, began to take definite shape in the minds of the military and naval authorities and their advisers.

When confronted with a scheme so far transcending all previous undertakings in magnitude, many vitally important questions press for answer. Thus:

1. Of the various types of machine—fighting, reconnaissance, bombing, and training—what number shall be set as a goal for active service at one time?

2. What shall be the technical characteristics, size, power, armament, etc., of the machines in these several types?

3. What wastage in such machines is to be anticipated?

4. In consequence, what numbers in each type must we be prepared to build within a twelve-month or any other specified time?

5. How many trained aviators will be required to maintain the desired number of machines in active service?

6. How many men must be put through preliminary training in order to secure the needful number of active aviators with the necessary reserves; or, in other words, how much raw material must be handled in order to secure the necessary amount of finished product?

7. How many mechanics and repairmen will be needed to keep this fleet of airplanes in all classes up to "concert pitch" and ready for instant service at any and all times?

8. Where and how are we to undertake to build the number of airplanes indicated as the necessary gross output, say for a year, in order to maintain the fleet continuously at proper strength? Or, put otherwise, we may perhaps well ask, What is the maximum number of airplanes which can be built in these various classes in the United States or by the United States without undue disarrangement of other needful war industries and of the irreducible minimum or civil industries?

9. To what extent will further demands be placed on our productive capacity by demands of our allies in Europe for air-

planes or engines in types which we may hope to produce with high economic efficiency, and to what extent may we expect to draw upon them for certain types—as, for example, the fighting scout—thus relieving the United States, to some degree, of attempting, at least at the start, to produce this final word in the evolution of fighting aircraft as developed on the battle-fields of Europe?

10. To what extent will the demands of our allies call for raw material, such, in particular, as airplane timber? Will the total demand exceed the presumable supply, and, if so, to what substitutes may we turn?

Immediately, answers to these questions are developed, even in approximate form, multitudes of further questions arise, some of which are of the most fundamental importance.

One of these is the question of standardization. To what extent shall an attempt be made to standardize the engine and plane, thus facilitating rapid and economic production, and to what extent shall several competitive types be employed, thus aiming at constant competition and evolution by a process of selection—the survival of the fittest? Advantages and disadvantages lie with either policy, and neither should be pushed to the extreme. Broadly speaking, the Germans, during the war, have adopted and worked consistently on the policy of a high degree of standardization and the limitation of the number of different types. Types or designs few in number and a consistent effort to improve and perfect those types or designs—such, in general, has been the German policy. On the other hand, the French and English have adopted a more open policy regarding the number of types and designs and have placed less importance on the economic results to be derived from close standardization.

Without attempting to define too closely the policy to be followed by the United States, it may be properly said that when a scheme so vast as that now under realization is in hand, economy of production becomes an imperative factor, and, to this end, some degree of standardization is necessary. On the other hand, the authorities responsible for the creation of this vast fleet do not intend to lose the advantage of competition and of the development and improvement which will come from a careful study of the results of actual service; and sufficient elasticity of program will be provided to permit of taking due advantage of the

results of experience as developed in actual service over the fighting lines, and also to permit of the influx of new ideas and designs as fast as they may be able to demonstrate, under suitable trial, their superiority over the existing forms and designs.

It is a commonplace of economic production that the greater the number of units built from a given design the less will be the cost of production per unit. Again, at the start and for the first stage in the program of production, some one specific design must be accepted and placed in production for certain determined numbers. Beyond this, repetition orders may be given or changes

American flying boat.

introduced as experience may indicate. Here is demanded the most careful adjustment of various factors calling for the exercise of the best judgment which can be brought to bear on the many-sided character of the problem.

Again, while speaking of the problem of standardization, it should be noted that, of the various types of machine, some are much more readily standardized than others. Thus the training or school machine is most readily standardized of all. Indeed, it is perhaps not going too far to say that this machine is already practically standardized for the English, Canadian, and United

States air forces. This does not mean that no further changes or improvements are to be expected in this type, but rather that the type as now approved seems, on the whole, to be so satisfactory as to justify production on a large scale and on a standardized basis and with the corresponding economy and production costs. On the other hand, the machines of the other types are more difficult of standardization, and the fighting or scout machine most difficult of all. This simply means that, with the changing developments over the battle lines and with the constant efforts of the enemy to improve his own machines, the program of design and production must be such as to permit, perhaps of rapid changes in form, proportion, power, speed, armament, and various other technical characteristics, in order that the machines in actual use over the lines may be as nearly as possible continuously responsive to the changing conditions to be met or to the improvements developed through scientific research or by inventive genius.

TYPES OF AIRCRAFT.

This will be perhaps a suitable point at which to speak briefly of the different types and forms of aircraft which have been developed under the urge of war conditions, and of the special purposes which they are intended to fulfil.

The principal types are:

1. Training machines.
2. Reconnaissance and artillery spotting.
3. Bombing.
4. Scout and fighting.

Training machines, so called, are intended to give the student aviator his first experience and training in the air. In the advanced schools of training, as referred to later, the candidate for aeronautic service is given further training in specialized types of machine, according to the character of service for which he may seem best fitted. In order, however, to develop confidence in the air and to learn the fundamentals of the art of flying, a machine is required of moderate speed, easy of manipulation, with good inherent stability and generally with the qualities suited to lay a foundation for further training in actual war machines.

For the very first stages and for familiarizing the candidate with the feel of the machine, with the nature of the controls, and with the first rudiments of the art, low-powered machines in-

capable of flying are used. Such machines are variously styled "grass-cutters," "penguins" (by the French), and various like descriptive terms. They are intended only to run along the ground, with perhaps an occasional short skim just above the surface.

With the development of some confidence and skill in managing the controls, more ambitious flights may be made, sometimes in a regular field training machine and sometimes in an intermediate type a little more advanced than the "grass-cutter."

For regular flights constituting full training, a machine of moderate size, weight, and power is required—typical weights ranging from 1200 to 1500 pounds, horsepower 80 or 90, and speeds of 70 or 80 miles per hour maximum.

For more advanced training, somewhat lighter machines with the same or higher power and comparatively higher speeds are employed.

Passing now to machines of direct military type, we find three chief functions to be fulfilled by such machines. These are:

1. Reconnaissance and artillery spotting.
2. Bombing.
3. Fighting.

In most cases, two or more of these functions are in some degree combined on one plane. That is, a reconnaissance machine should also be able to fight, likewise with a bombing machine, while the general duty of reconnaissance is always a part of the work of a machine in the air.

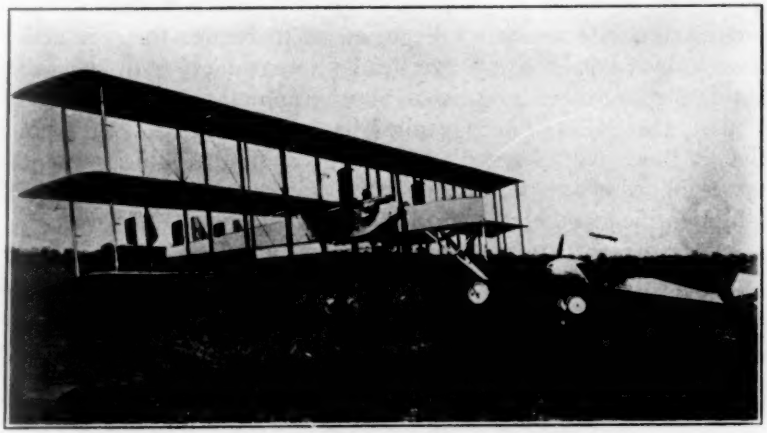
Nevertheless, the three types of function are measurably distinct, and the characteristics of the machine and its equipment are determined primarily in accordance with the function which is to be paramount.

Thus the primary function of the reconnaissance machine is observation and photography, and the characteristic machine of this type will carry two men, a pilot and an observer.

The two instruments for reconnaissance work are the human eye and the camera. The former is used for incidental and general observations, and especially for those which must be made available immediately to the higher command behind the lines. Such observations relate to the movement of troops, munition trains, supplies, the fall of shell, location of enemy's batteries, concentration of troops, etc.—in short, anything the immediate knowledge of which may be of value to the higher command.

The camera is used principally for purposes of map making, and especially with reference to the keeping of maps up to date with all information relating to the permanent structures of the enemy, trench lines, specially fortified positions, entanglements, dug-out openings, gun positions, munition depots, shell dumps, etc.

It is an interesting thought that through the human eye and wireless telegraphy information may be made immediately available to the command in the rear, and movements, changes, and formations described as they occur; while with the eye of the camera, and without the human brain to interpret the light stimuli received, the information hidden in the photographic plate or



Large Italian Caproni tri-plane.

film must await development and printing before it becomes of direct use for military purposes. Both means of gathering and reporting information are, however, necessary. The camera cannot give results immediately available, while the eye, even in conjunction with the brain, cannot record with accuracy the many details needed for the preparation of adequate military maps. Thanks to improvements in photographic cameras for such purposes, it is now possible to prepare maps day by day, based on photographic records of the day, and have them ready for use within a few hours of the return of the plane bearing the exposed plates or films; and, thanks to the marvellous skill which practice in the interpretation of photographic records gives, it has been

found possible to determine with high precision the location and character of the defensive and offensive dispositions of the enemy in the way of permanent structures.

A word may perhaps be said here regarding the subject of camouflage—the disguise of strategic points or features of military structures, such as gun positions, dug-out exits, etc., in such manner as to make their detection difficult or impossible, especially from airplane photographs. Here, as elsewhere, we have a constant struggle between the defensive and the offensive—between the development of skill in the art of concealment and skill in the art of detection. They are developing measurably, perhaps, on even terms. Given time and suitable materials, many important strategic positions and features may, in the hands of skilful camoufleurs, be so disguised as to render their detection practically impossible by overhead photography. On the other hand, the scientific analysis of photographic printing in its relation to the objects photographed has proceeded to such a point that in the hands of a skilled interpreter of such photographs the most innocent and natural-looking features have been detected and identified in their true military character.

But to return to the reconnaissance machine. The primary purposes are, as we have seen, to report information of immediate significance and to gather photographic material for the correction and extension of military maps. To this end, the primary equipment needed comprises the observer, photographic apparatus, and a wireless outfit. The pilot flies the machine as low as anti-aircraft attack and other circumstances will permit, and the observer proceeds with his work. If attacked, the machine should have some means of offence, but its primary purpose is not to fight, but to gather information. It must depend primarily on the fighting machines which accompany reconnaissance machines to take the brunt of the fighting, to ward off enemy attacks, and to defend them from disturbance by the enemies' fighting planes. If attacked in force or outnumbered, it is the plain duty of such machines to make the best escape possible and return behind the home lines with such information as may have been gathered. Nevertheless, reconnaissance machines should be equipped with one or more machine guns in order that they may have some general means of offence in case of need.

Some further emphasis should perhaps be laid on the subject

of artillery spotting as a function of this general type of machine. In fact, the machines allotted to this duty may perhaps be considered as a special group or section of the general type of reconnaissance machines. The importance of artillery spotting has been recognized from the first months of the war. The spotting machines hang aloft high in the air, circling about, watching the fall of shell from far-distant gun positions and sending, by wireless, information serving to correct the aim.

For the general purpose of reconnaissance and artillery spotting, machines of weight and speed intermediate between the bombing and the fighting machines are employed. Speeds of one hundred miles per hour and upward are typical of the general type of reconnaissance airplane.

Taking next the bombing machine, two types are recognized—the heavy and slow and the light and fast. The former are intended for night work, when the machine may fly lower and slower than for work in daylight, and may therefore be given a heavier load of offensive burden in the form of bombs; while the latter, for use without protection from the darkness, must be given higher speed and be capable of rising to heights above anti-aircraft range, and cannot therefore be given as heavy a load of offensive burden. Bombing machines usually carry two or three men, sometimes more, and have speeds of from 80 to 110 or 120 miles per hour. The special equipment of the bombing machine comprises the bombs, the apparatus for carrying and releasing them as desired, singly or in groups, and the aiming device. In addition, the bombing machine should carry one or more machine guns for general offence. The tendency will be presumably to increase the offensive armament of such craft, and we may anticipate a tendency toward more and heavier guns for offensive purposes on machines of this type.

But little can be said regarding the bombs themselves, the method of carrying and dropping them, or the aiming devices. These are matters over which a reserve must be drawn, for obvious military reasons. The interesting character of the problem to be met by the aiming device may, however, be briefly noted.

The airplane bomb is allowed to fall under gravity, which is, therefore, the only force acting to bring the bomb to the earth. It has, however, the velocity of the airplane at the instant of detachment, and hence will move in a path determined as the

resultant of these two velocities—that gradually acquired under gravity and that due to the velocity of the plane. According to the well-known principles of mechanics, this would result in movement along a parabolic path, were no account taken of air resistance. Aside from the latter, therefore, observations must be taken which will determine the altitude of the plane at the instant of dropping and also the speed relative to the ground. With these known, the bearing of the target in a vertical plane can be determined at the instant when the bomb should be released in order to reach the target. A telescope may be set for this bearing, and when the target reaches the cross-hairs the bomb may

Italian reconnaissance plane.

be released. The realtive simplicity of this operation needs, however, supplementary correction to allow for the resistance of the air, due to which cause the path followed is not an exact parabola; also due to the drift of the machine under the influence of the wind itself, often variable between the plane and the ground. Again, the nature of these corrections varies according to the form and proportions of the bomb, so that for each design final corrections must be worked out by trial.

After all this, it must be admitted that the target practice realized in bomb dropping is not, and cannot be expected to be, very close. From a height of 10,000 feet the time required for the bomb to fall under gravity is about one-half minute, and a

very slight departure from the exact conditions when it is released may carry it wide of the mark at the ground. The only apparent way to realize effective work with bombs dropped from aircraft is either to fly low and reduce the errors of aim or to use planes in very large numbers, so that out of the hundreds or thousands of bombs dropped a fair number may be expected to find the military objective.

We come now to the fighting machine *par excellence*—the machines whose duty it is to protect reconnaissance machines in their work, to attack and drive away enemy fighters, to attack enemy reconnaissance machines in their work of spying out home defences or operations, and generally to serve as the fighting support of the reconnaissance machine in its work on the enemy's side of the line, and to attack and drive off the reconnaissance machines of the enemy or give battle to the fighting machines which may accompany them. In addition to this, fighting machines are being used more and more for direct offence in connection with drives against the enemy. The public press has carried many accounts of the use of aircraft in this manner, flying low and attacking trenches, reserve formations in the rear, and making themselves a significant and effective element of the offensive operation.

In the early months of the war aviators were armed with carbines or rifles as the chief arm of offence. These soon gave way to the machine gun as a vastly more effective agent. There are, in general two types of mounting, fixed and movable. In the former the gun is fixed to the machine and is aimed by aiming the machine itself. Practically all fighting airplanes are now of the tractor type, and this immediately raises the question of firing ahead with the propeller whirling directly forward of the nose of the machine. This problem has been solved in three different ways: (1) mounting the gun on the upper plane and firing over the propeller; (2) mounting the gun between the planes and firing through the propeller, with the shots so synchronized as to miss the blades themselves; (3) firing through a hollow propeller shaft driven by gearing from the main or engine shaft.

The first mode of mounting avoids all difficulty, so far as the propeller is concerned, but places the gun itself out of the ready reach of control of the pilot. The second mode of mounting has attracted much interest by reason of its novelty and boldness of

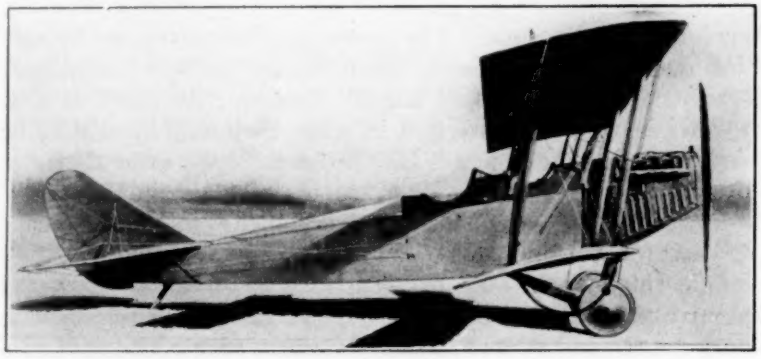
concept. Originally due to Garros, it was quickly adopted and developed with improvements by both the Germans and Allies. The details of the arrangement vary, but depend usually upon some method of arresting or preventing fire at such instants as would bring the blade in the way of the bullet as it leaves the gun. The usual speed of fire of such guns is in the neighborhood of 600 shots per minute, and, since propeller speeds are usually twice that and more, it is readily seen that there can be allowed only one shot for about two revolutions of the propeller. There is, therefore, abundant chance for this shot to get through, if properly timed, without risk of piercing a blade. In case of delayed ignition the time relation may be deranged and blades are sometimes hit. As a rule, no great damage is done except to put a small hole in the propeller. In some cases, however, if the blade is in any degree shattered, further breakage might follow, with the result of throwing the propeller out of balance, loss of propulsive power, and probable disaster to the machine. The chances of such result are, however, remote, and pilots of fighting machines take no thought of any such contingency in connection with the other hazards to which they are subjected.

The third method of firing—through a hollow propeller shaft—avoids all need of synchronizing the gun with the propeller, but it requires a separate propeller shaft geared to the engine shaft. This, however, is coming to be, if anything, an advantageous mode of drive, due to the fact that, with propellers of the size suitable to absorb the horsepower required, the efficiency at high rotative speeds is poor. This is a fact well known in the mechanics of the air propeller and which cannot apparently be avoided. For the sake of high propeller efficiency, therefore, there is constant need to keep rotative speeds down. For the sake of a higher ratio of power to weight in the engine, there is a constant tendency to push rotative speeds up. So long as the propeller is carried directly on the engine shaft there is no way of reconciling these opposing tendencies. With an engine of the V-type, the propeller shaft may be comfortably located between the sides of the V, above the engine shaft and geared to it by appropriate reduction gearing. In this way any desired rotative speed may be given to the engine with any desired speed for the propeller, while the hollow propeller shaft provides a pathway for the bullets without danger of interference with the propeller

blades. Each of these three modes of fixed mountings has its advocates and special adaptations. Only continued experience will serve to finally decide which, if any, will be the final approved form.

With the other general type of mounting, the gun is so carried as to permit swinging in azimuth and changing in elevation in such manner as to give a wide arc and range of fire, practically in all directions except where prevented by the parts of the plane.

Fighting machines are made in both the one-place and the two-place types. In the former the single pilot must both guide and fight his machine. In the latter the duties may be divided: either pilot may control the machine, and both are provided with



American training plane.

machine guns for offensive use against the enemy. In this manner the machine is always under control so long as both pilots are not fatally or seriously injured.

Machine guns are of two general types. In one the gun is operated direct by the force of the recoil, while in the other the operating mechanism is actuated by gas under pressure drawn from the barrel a little back of the muzzle. Without attempting to specify too closely the machine gun arrangements in use by the Allies, a few typical arrangements used by the Germans may be mentioned.

In a large bombing plane, guns are mounted firing ahead, on either side and to the rear through a longitudinal tunnel under the length of the fuselage.

A fast fighting plane mounts three fixed guns firing ahead and converging at a point about fifty yards ahead of the plane.

Another fighting plane mounts a forward pivotal gun and a rear gun which may be depressed to shoot downward through a tunnel in the fuselage behind the pilot.

Other types mount two guns firing forward through the propellers by means of a synchronizing device.

Arrangements and mounts for machine guns on aircraft are undergoing rapid development and change, and the approved system of to-day may be to-morrow discarded for a more effective arrangement. Broadly speaking, the present tendency in airplane armament is toward more guns, heavier guns, and more effective all-round offence.

The chief military equipment of the fighting planes comprises, therefore, machine guns. The special problem presented by machine gun sights for use in aircraft can be only mentioned. Broadly, it is that of making due allowance for the speed of both airplanes in whatever direction in space they may happen to be going at the instant of fire. This becomes, in the general case, a most complex problem, involving rapid judgment in the use of the intricate form of machine gun sight which is intended to serve as a basis for its solution.

One simple case may be mentioned in order to show the deceptive character of ordinary observation. Suppose the machines are circling around a common centre at opposite ends of a diameter and at a speed of about 100 miles per hour or, say, 150 feet per second, and suppose that the circle is 1000 feet in diameter. Then as each pilot looks at the other there will be no change in relative position or attitude of the machine, and if, on the basis of this superficial observation, a point-blank aim were taken, the bullet would fly some 120 feet wide of the mark.

Such cases and many others still more complex must be met and quickly judged in the use of the machine gun firing from one airplane against another.

While thus some attempt has been made to classify and discuss the functions of the various types of airplanes used for military purposes, too much stress must not be laid on arbitrary classifications, which may rapidly become obsolete in the advancing art of airplane warfare. In particular, recent months have seen notable advances in the size of military aircraft, especially

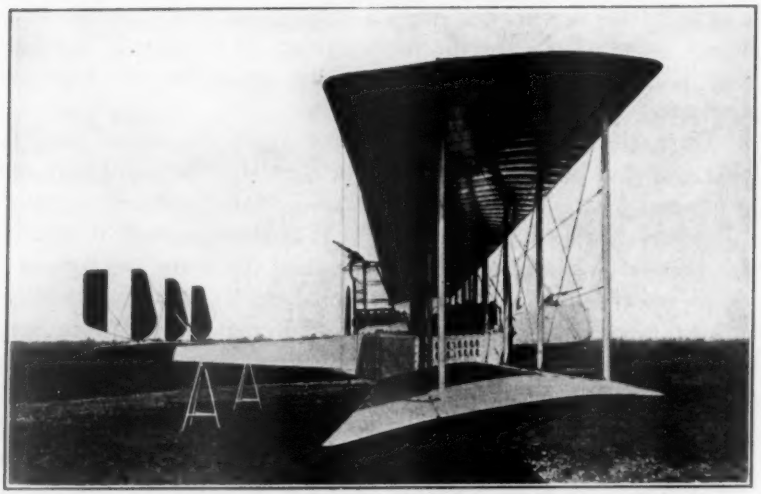
as illustrated by the Italian Caproni, the British Handley Page type, and the German Gothas. Such machines, often of 700 horsepower and upward and capable of carrying 10 to 20 men, may be used both for fighting or bombing, or, in fact, for any purpose which may be realized by the ability to carry great weights at fairly high speeds and including a considerable crew of men with offensive gun armament, both in number and calibre far in advance of the one or two conventional machine guns now carried as the typical airplane offensive armament. It should be said, however, that such machines are classed in the heavy bombing group.

With these remarks by way of reference to the general problems involved, we may advance a step nearer and examine more closely some of the specific problems which are met at the very start of the development of an actual program for the American air fleet.

First, the engine: What type or types of engine shall be used, of what horsepowers, what designs shall be employed, and in general what shall be the first step toward the development of the power plant of the airplane? It is perhaps well to note at this point that as between the engine and the plane the former is the more difficult of construction, and, broadly speaking, the limitations imposed on our production of aircraft will be more likely to come from the side of the engine rather than from that of the plane. An airplane has been aptly termed an engine with wings, and, while much depends on the design and construction of the wings, yet broadly it remains a fact that the number of effective aircraft which we can maintain over the fighting lines will depend primarily on the number of engines which can be built and maintained in effective reliable operation.

In reaching a decision on this point many factors required most careful consideration. The best engines developed in Europe under the stress and urge of war conditions should obviously be better adapted to war airplanes than those developed in the United States during the same period. Such superiority must be accepted as a necessary and natural result of the factors determining the situation. Freely granting this, however, it must be likewise admitted that these engines are for the most part not well adapted to standardization and for rapid production in large numbers. Thus, for example, the builders of one of the very best of the English designs were able to secure a production of

only about two hundred engines per year, and the statement was freely made that to produce this engine in the United States it would be practically necessary to bring over the organization of this factory complete and set it down in the States. While this example is perhaps extreme, it is nevertheless true that European designs are generally not well adapted to standardization to the extent necessary if we are to realize the enormous production contemplated. It becomes, therefore, a matter of choice. Either the design must be such as to admit of standardization and construction scattered abroad through and among many



Large Italian Caproni biplane.

shops, or else we must accept a serious sacrifice in the quantity of production.

Confronted with a choice among these conditions, the obvious course seems to be to realize, so far as may be, a design paralleling the best European practice and at the same time adapted for standardized methods of production. The components thus sought to be combined in the design should, therefore, be these:

1. The best European design and technical practice.
2. The best of American design and technical practice.
3. Standardization for economic and rapid quantity production.

The story of how the design of the so-called "All America" or "Liberty" engine has developed in accordance with these purposes cannot be told here in more than bold outline.

It is not too much to say that the design and production of the first examples of this engine were little less than an industrial miracle.

In the early days of June two of the leading designers of internal-combustion engines in the country, strangers personally, though well known to each other by reputation and achievement, were called by telegraph to Washington, placed together in a room in the Willard Hotel, and told to design the "All America" engine. With reasonably full information at that time available regarding the design of the leading European types of engine, with the best practice of this country a part of their commonplace knowledge, and with a keen appreciation of the stupendous task of production opening above the horizon, these two designers approached their task. Other engineers and designers of note were called in conference as occasion required. As fast as features and details were determined, they were rushed to draughtsmen installed in a building available at the Bureau of Standards. This work was further supplemented in draughting-rooms scattered over the middle West until some two hundred or more draughtsmen were working in shifts on the detailed structural drawings. These again, as rapidly as completed, were rushed to the manufacturing plants best able to turn out the structural elements, and thus in an incredibly short time the elements of this engine were under construction in some twelve different establishments from the Pacific Coast through the middle West and East, and four weeks from the day when the two designers sat down in their room in the Willard Hotel the first engine was assembled in Detroit, placed on an express car with two special messengers, and rushed to Washington, where it arrived on July 3.

It must further be noted that this piece of design work gave really four engines instead of one. The essentials of design involved in reality a single cylinder and its corresponding moving parts. With these determined, it was a relatively simple matter to provide for combinations into units of four, six, eight, and twelve cylinders each, giving four engines of from 120- to about 350-horsepower capacity. The first shop order comprised five

engines of the eight-cylinder and five of the twelve or twin six type, and it was the first of the eight-cylinder type to reach Washington thirty days after the inception of the design as noted above.

The next stage in the program was a series of tests carried out on these first engines and intended to prove out the design in every respect before passing it for quantity production. It would be too much to expect that such a design could be perfect and definitive in every respect. In fact, certain matters of proportion and dimensions could be determined only as the result of test or experience. We must further remember that an aeronautic engine is to really do its work at elevations of 12,000 to 15,000 or 18,000 feet above sea level, while ordinary testing facilities, such as those at most shops and laboratories, are at elevations, for the most part, of only a few hundred feet above sea level. The conditions which prevail at Washington or Detroit or Chicago or at the new aeronautic laboratory at Langley Field, near Hampton, Va., furnish, therefore, no suitable environment within which to determine just how such an engine will perform at an altitude of 15,000 feet. Confronted with this situation, we must either go where suitable conditions do prevail or else provide for them artificially. Actually both courses were taken.

A motor truck was fitted up as a portable testing laboratory with suitable dynamometers and other measuring equipment, the engine was mounted thereon, and the whole combination was shipped to Colorado, where the motor truck was run up the grade of Pike's Peak and the engine tested out at two or three different altitudes.

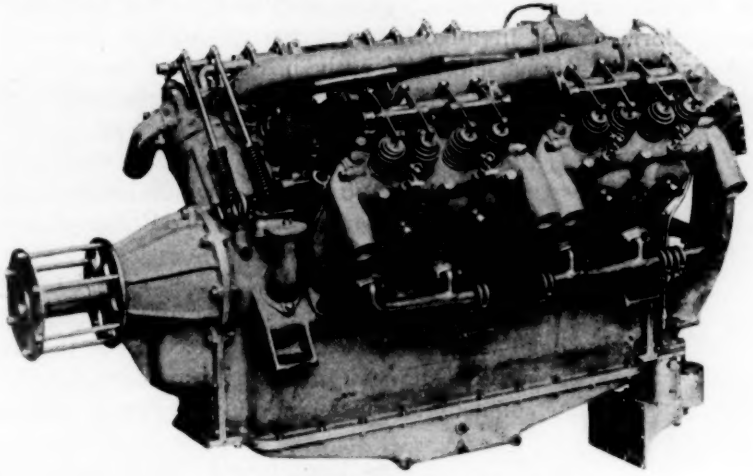
In the meantime a test chamber for artificially producing conditions similar to those met with at various altitudes was under construction at the Bureau of Standards in Washington and with special reference to a series of tests and investigations on aircraft engines under conditions similar to those which would be met with in free flight at various heights above sea level.

By means of this special equipment, an aeronautic engine may be placed under conditions substantially the equivalent of those met with at any stated altitude, and including any specified air-pressure, temperature, and humidity. This will give sets of controlled conditions under which an engine may be operated at any power and for as long a period as may be desired. The rate of change from one condition to another is also under control, so

that the conditions met with in an aeroplane in leaving the ground and mounting to an altitude of, say, 18,000 feet in thirty minutes may be closely paralleled.

This experimental equipment, it is expected, will play an important part in the final development of the Liberty engine and its various special features, such as radiator proportion, carburetor adjustment, muffling, etc.

Regarding the selection of types and characteristics of planes, some reserve must be maintained. As previously noted, the training type has been selected and has been adapted as standard by the British, the Canadian, and the United States governments.



Modern aeronautic engine, 8-cylinder type.

Regarding the design characteristics of the other types, it must perhaps serve to say that the best results of English, French, and Italian practice have been carefully studied and freely used in the selection of type forms and design characteristics for machines of the strictly military class.

But for a great air fleet something more is required than airplanes and engines. Airplanes do not fly and manœuvre themselves, especially not in the manner characteristic of modern air tactics. The human mind and purpose, the brave heart, dauntless courage—these latter are needed to give to the airplane its full significance as a factor in modern warfare. This means the human element, the aviator.

What, then, is the military aviator? A product of what school of training? In what way are we now working to develop this all-essential factor in the air fleet?

The human aviator, developed to the highest degree, is in effect a human bird, a man so developed in his muscular and nervous organization that the airplane has, in effect, become a part of himself—a man whose reactions in the air are as automatic as are those of a bird. But few, however, reach this far-away ideal, and between such goal and the unskilled efforts of the beginner there are indefinite grades of skill, shading one into another and marking the path of progress between the awkward efforts of the beginner and the finished grace and skill of the bird-man. Here, moreover, as in all other branches of human endeavor, there is reserved for a selected few the possibility of the achievement of almost incredible skill—the real ideal of the bird-man. Such are few in number, relatively, and short of these rare prodigies of grace and skill there is fortunately a degree of skill quite sufficient for most military operations and to which larger numbers can attain with average endowments as a foundation and with reasonable perseverance in their development.

The steps actually taken by the United States Signal Corps for the development of aviators for the army are briefly as follows:

Eight educational institutions were first selected for the development of schools of preliminary training for aviation recruits. These institutions, distributed over the United States, are as follows:

The Massachusetts Institute of Technology,
Cornell University,
Princeton University,
The Ohio State University,
The Universiy of Illinois,
The Georgia Polytechnic,
The University of Texas, and
The University of California.

These schools, when equipped and in full running order, are intended to have a capacity of two hundred students (or cadets, as they are called), divided into eight groups or classes. The course is eight weeks in length, and twenty-five cadets are entered at the beginning and twenty-five graduated at the end of the course each week. This secures a steady stream of young men

moving along through the eight classes, one class per week, and would thus secure an output of twenty-five students per week for each of the eight schools, or two hundred per week were there no wastage by the way. This would secure a maximum number of graduates of this preliminary training of about 10,000 per year. The capacity of these schools may be greatly increased if necessary, and other schools may be added as occasion may require.

This preliminary training does not include work in the air. It includes, however, certain very necessary courses of instruction intended to give the young aviator some familiarity with the following subjects: military science, practical and theoretical; signalling and radio work; gunnery nomenclature, machine guns, gun sights, fighting tactics, bombs and bomb dropping; theory of flight, cross-country flying, map reading, meteorology, night flying, instruments and observations; types of airplanes, nomenclature, rigging, care, repair; types of internal-combustion engines, laboratory training, care of engines and appliances, troubles and their detection and treatment; airplane tactics, reconnaissance work, artillery spotting, and photography.

With satisfactory progress in these subjects the graduate of the preliminary training is hurried on to actual work in the air at the various flying fields which have been, and are still being, developed in various parts of the United States.

There are some eighteen flying fields now organized in the United States, and more are in contemplation. The number of planes at these fields may vary from twenty or thirty up to one hundred or more.

It will be understood that a field with any given number, such as thirty-six machines, can have under training at any one time several times thirty-six aviators.

In addition to these fields in the United States, use is also made of the British training field at Borden, near Toronto, and certain graduates from the preliminary training are sent direct to undergo their entire training in the air at the fields in France.

It must not be supposed, however, that all the air training is acquired at one place or following a single so-called course. As a matter of fact, the whole curriculum is quite extended and includes at least four divisions or grades, as follows:

1. Elementary training intended to teach a man simply to fly;

to give him confidence in the air and skill in controlling the slower or training machines under ordinary aerial conditions.

2. Training on military machines, including the development of the skill needed for handling the swifter types of planes, practice in machine gun target practice, bomb-dropping practice, radio work, reconnaissance work, artillery spotting, photography.

3. Special or advanced training on military machines, especially of the fighting air-scout types, including trick flying, special tactics, or other special training, according to the adaptation of the student.

4. Final training and practice behind the lines in France and, as nearly as may be, in the atmosphere of the front.

INSTRUMENTAL AND MILITARY EQUIPMENT.

The man and the machine do not quite fill the measure of the requirement for an effective military aircraft. There must be added a series of instruments and items of military equipment which can here be only briefly and somewhat imperfectly noticed.

This secondary equipment divides itself into two main groups —navigating instruments and military equipment.

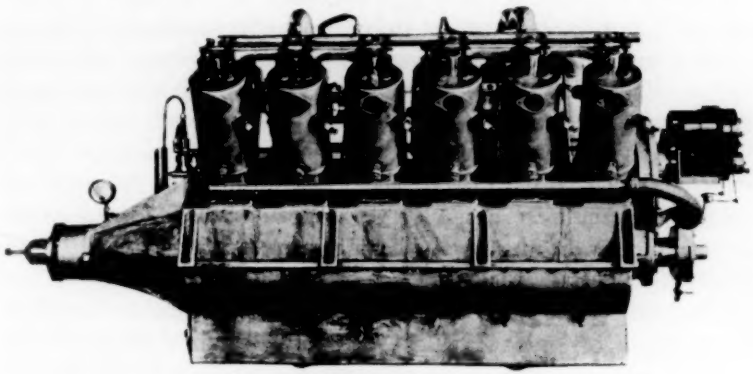
Comprising the former, the following may be mentioned:

1. Altimeter.
2. Airspeed meter.
3. Angle of incidence indicator.
4. Revolution counter and tachometer.
5. Watch.
6. Thermometer.
7. Vertical direction indicator.
8. Drift meter.
9. Compass.
10. Gasoline supply indicator.

No one machine is likely to carry all of these instruments. In fact, in many cases the altimeter, compass, watch, and revolution indicator are considered quite sufficient.

Referring to these instruments briefly, the altimeter is an instrument for measuring or indicating the altitude of the airplane above the earth's surface. It consists usually of some form of aneroid barometer adapted to this special purpose and graduated so as to read altitude above the sea level in either feet or metres, as desired.

The airspeed meter is an instrument for indicating the speed of the airplane through or relative to the air in which it is moving. Several forms have been devised, those most commonly used depending upon either the Pitot tube or the Venturi tube principle. In no case will the airspeed meter give any reliable indication of the speed over the ground. This will depend on the speed through the air and on the wind velocity or the speed of air movement relative to the ground. Thus with an airplane flying into a head wind with a velocity of thirty miles per hour the speed through the air may be ninety miles per hour, while the speed over the ground will be only sixty miles per hour, while if flying with the same wind the speed over the ground will be one hundred and twenty miles per hour. The indications of the



Modern aeronautic engine, 12-cylinder type.

airspeed meter have, therefore, small value for purposes of navigation, properly speaking, but they do have some relation to the proper speed of the plane with reference to its load and climbing angle.

The angle of incidence meter is intended to show the angle between the chord of the main planes and the direction of its movement. This indication also has chief relation to the safe and proper condition of the plane with reference to its load and climbing angle.

The revolution counter and tachometer is intended to give an instantaneous indication of the rotative speed of the propeller shaft and a continuous total of the same over any trip or period of time. Though usually different in form, it serves the same

purpose as the corresponding and familiar instrument found on every automobile. Since, moreover, the slip of the propeller is fairly uniform under uniform conditions, the instantaneous indications of the shaft may be made to give an indication of the speed through the air which may be checked against the indication of the air speed meter.

The significance of the watch is obvious, and it is commonly worn on the wrist, also for obvious reasons.

The thermometer is of significance only for meteorological observations and may or may not be included in the equipment, according to the purposes in view.

The vertical direction indicator is often of significance when flying in the night or in a fog or cloud. Especially in the latter case, if the machine is circling, it becomes very difficult to determine by the ordinary sense of balance or orientation the direction of the true vertical. The principles of the gyroscope are found most available for realizing an instrument which may be made to give at all times an indication of the true vertical.

The drift meter is an instrument intended to give the angle between the actual path of forward motion and the fore-and-aft line of the machine. It is clear that if an airplane is flying side to the direction of the wind, then, relative to the earth, the machine will sidle off obliquely along a path the direction of which will lie between that of the propeller shaft and that of the wind. The actual direction of travel relative to the earth is of importance in many military operations, especially in bomb dropping, and some means for obtaining an indication or measure of this angle is therefore necessary for such operations. One form of drift meter which illustrates the principle usually employed comprises a form of telescope pointing vertically downward and with a grating of parallel spider-web filaments. Looking through this telescope on the ground below, the lines of flow backward of objects on the ground may be observed, and the telescope may be revolved about its axis until such lines are parallel to or along the grating filaments. The angle made between those filaments and the fore-and-aft direction is then read on a suitable scale, thus giving the angle of drift.

The use of the compass is too obvious to need special note. The form commonly employed is a special construction of the so-called marine or card form adapted to aircraft service.

The special military armament of airplanes comprises the machine gun, the bomb, and the radio equipment. The machine gun and the bomb have been already noted in connection with the fighting and the bombing types of airplanes.

Regarding the radio equipment, reference has been already made to the function of the reconnaissance and spotting plane—the prompt report of information back to the higher command. To this end, wireless telegraphy has been developed to the point where it has played a most important rôle. The modern reconnaissance or spotting airplane is therefore fitted, at least, with a sending radio outfit capable of sending messages to points several miles distant and of thus communicating instantly the results of their visual observations. This outfit requires a source of electric energy, and this requires a suitable generator and a source of power. The latter is often found in the movement of the plane, the usual type of generator comprising a form of air-wheel or propeller actuated by the movement through the air and thus driving an electric generator suited to the requirements of the radio equipment.

The full development of wireless telegraphy, however, implies receiving as well as sending. This, with the noise inseparable from the operation of the airplane, presents many very difficult problems. The results realized here can only be referred to with reserve, but it may be said that gratifying progress has been made in the solution of such problems, and within certain ranges messages may be received as well as sent.

This permits of the aviator keeping fully in touch with his base when in the air, and also lays a foundation for squadron airplane tactics and evolution, not readily practicable without some means of transmitting and receiving commands from one plane to another.

But the plans for a great air fleet are not limited to use by the army and on the fighting lines in France or elsewhere. There is also the work of the navy, with its squadrons of seaplanes for coast patrol and its scouting seaplanes for service against the submarine.

Plans have been formulated for a number of coast patrol centres along the Atlantic, as well as on the Pacific and in the insular possessions of the United States, all for our own defence. In addition, the United States is counting on furnishing for the

coastal waters of France and England a still larger number of squadrons of seaplanes for scouting and patrol, with special reference to submarine detection and offence.

Specific numbers cannot, of course, be mentioned, but the aggregate of the seaplane squadrons, either provided for or in contemplation, will represent a very significant addition to the coast patrol forces of the European Atlantic waters and a good beginning on an adequate patrol service for our own coasts.

For the training of pilots for these seaplanes there have been also established, at a series of points on the sea-coasts of the United States, training schools where a large number of men have been and are continuously under instruction and training for this branch of the service. The general character of the training is similar to that employed for the development of the pilot of the land machine and need not be here considered in detail.

For coast patrol work, seaplanes are used either of the pontoon or flying-boat type and one-place or two-place in carrying capacity. They are provided with machine-gun offensive armament, and may carry a further weight in bombs, according to size and character of service.

The general problems arising in the navigation of seaplanes, their equipment with military armament, etc., are entirely similar to those for airplanes used for service over the land, and do not, therefore, call for further special notice.

Perhaps the most distinguished general characteristic of the development of an airplane service is the rapidity of change in types of machines and in standards of performance. The three years' progress of war on the western front in France has seen the rise and eclipse of dozens of types of machines of various technical characteristics and qualities. There are now in use along this front perhaps some two dozen types of machines, but how soon others of improved characteristics may appear and relegate most of them to the rear or for secondary service, the future of to-morrow or next week or next month or next spring alone can tell. Herein enters one of the difficulties of standardization. Unity of design and standardized construction through templates and gauges are a necessity for the most rapid industrial production, but no such condition can be allowed to stand in the way of improvement in design and technical quality, and so we must adjust ourselves to some compromise which will secure the maxi-

mum industrial production compatible with a quick response to the changing conditions developed by the military demands of the situation and to the advance of the art through research, invention, and experience.

The great war has now reached a stage when in a very real sense the eyes of the world are upon us, and our allies echo the thought that the way to victory lies through the air, and they are now awaiting the moment when we shall be able to lend our effort in such degree as shall furnish a really determining factor.

In no way can we do this so effectively or so quickly as through the air. If we stand true to our traditions of 1776, of 1812, of 1861, of 1898, we shall not fail to measure up to the needs of the situation, and we shall, with our pilots in the air, our boys in the trenches, and our sailor lads on the deep, finally be able to justify the reasonable expectations of our allies as the last great source of power in the struggle for the overthrow of the great arch-enemy of government of, by, and for the people.

Increase in Production of Natural Gas. ANON. (*U. S. Geological Survey Press Bulletin*, No. 341, November, 1917.)—Statistics just compiled under the supervision of J. D. Northrop, of the United States Geological Survey, Department of the Interior, show that the volume of natural gas commercially utilized in the United States in 1916 was greater than that so utilized in any other year in the history of the natural-gas industry. The volume used, which amounted to 753,170,253,000 cubic feet, constitutes a new record, exceeding by nearly 125,000,000,000 cubic feet, or 20 per cent., the former record, established in 1915. The average price of this gas at the point of consumption was 15.96 cents a thousand cubic feet and its total market value was $120,227,468, a loss of 0.16 cent in unit price, but a grain of $18,915,087, or 18.6 per cent., in total value compared with 1915.

The general increase in the production of natural gas in the United States in 1916 is attributed principally to an enormous expansion of the casing-head gasoline industry in all natural-gas producing states and to a greatly augmented demand for natural gas as fuel by industries engaged in the manufacture of munitions of war. The influence of this demand is shown in the increase in the volume of gas distributed to industrial consumers and in the increase in the value of gas consumed, its effect being sufficient to lower the average price per thousand cubic feet of all gas sold in 1916 1 per cent. as compared with 1915.

Carbon Tetrachloride as a Cleaning and Solvent Agent. ANON. (*Quarterly of the National Fire Protection Association,* vol. xi, No. 2, p. 173, October, 1917.)—Carbon tetrachloride is a water-white liquid having, when pure, a pleasant odor quite similar to that of chloroform. The commercial product usually contains sulphur impurities which impart a somewhat disagreeable odor. The specific gravity of the liquid at 32° F. is 1.632 and the boiling-point is 169° F. The specific gravity of the vapor is about five and a half times as great as that of air and about twice as great as that of the lightest napthas. The difference in specific gravities of the vapors of carbon tetrachloride and naphtha is not sufficiently great, however, to overcome the tendency which all vapors have to diffuse one within the other, and the two vapors do not separate, once they have become thoroughly mixed. The two liquids also show no tendency to separate after mixing.

Carbon tetrachloride is an excellent solvent of animal and vegetable fats, oils, varnishes, waxes, resins, mineral oils, paraffin tar, etc. It is non-inflammable and non-explosive. Combustion cannot take place in its vapor, due to the absence of oxygen. For that reason it extinguishes small fires in enclosed spaces when thrown into them. The toxic properties of carbon tetrachloride are of importance where large quantities are used and no provision is made for removing the vapors. Its effect on the human system is the same as that of chloroform, producing anæsthesia, though not as powerful in its action.

Until recently the cost of manufacture of carbon tetrachloride has been so great as to prohibit its general technical application, although for cleaning purposes, such as degreasing wool and removing oil and grease spots from finished cloth, it is fully as efficient as naphtha. Owing to this property, it is being used in a large number of patented preparations intended for use as cleaning agents, and is being sold under a variety of special trade names. These preparations sometimes contain other substances besides carbon tetrachloride, but they generally possess little or no advantage over the latter.

On account of its non-inflammability and property of smothering small fires, carbon tetrachloride is being sold to-day as a fire-extinguishing agent. In this rôle it has, however, the disadvantage of liberating large quantities of suffocating and poisonous gases, and it is necessary to confine the vapor to the immediate seat of the fire. Its high cost, despite further recent reductions in price, is still the one serious drawback to its more general application, but the many advantages which carbon tetrachloride possesses over naphtha in point fo safety make its use very desirable wherever practicable. The cost can be considerably reduced in many instances by reclaiming the spent solvent by distillation and by taking advantage of the fact that a certain percentage of naphtha can be added without making the mixture inflammable.

OUTLINE OF COLLOID CHEMISTRY. I.*

BY

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ADSORPTION OF GASES, LIQUIDS AND SOLIDS.

INTRODUCTION.

In 1861 Graham [1] pointed out that substances like potassium hydroxide, potassium sulphate, magnesium sulphate, sugar, and alcohol diffuse much more rapidly in aqueous solution than hydrated silicic acid, hydrated alumina, starch, dextrin, the gums, tannin, albumin, gelatin, etc. Since these latter substances are apt to occur in a gelatinous or non-crystalline form, Graham suggested calling them "colloids," from the French word for glue. Substances which diffused readily were to be called "crystalloids," because most of them crystallize readily. Graham believed that the distinction between a crystalloid and a colloid was due to some molecular condition. Though modern colloid chemistry begins with Graham,[2] his distinction between crystalloids and colloids has been dropped. We now speak of a colloidal state instead of a colloidal substance, and we call any phase colloidal when it is sufficiently subdivided,[3] the particular degree of subdivision being quite arbitrary.

According to this definition, colloid chemistry is the chemistry of bubbles, drops, grains, filaments, and films. At first sight this might not seem an important branch of chemistry, either theoretically or technically; but this opinion changes when we consider that a knowledge of colloid chemistry is essential to anybody who wishes to understand about: cement, bricks, pottery, porcelain, glass, enamels; oils, greases, soaps, candles; glue, starch, and adhesives; paints, varnishes, lacquers; rubber, celluloid, and other plastics; leather, paper, textiles; filaments, casts, pencils and cray-

* Based on a paper presented at the meeting of the Section of Physics and Chemistry held Thursday, January 11, 1917.

[1] *Phil. Trans.* **151**, 183 (1861); *Jour. Chem. Soc.* **15**, 216 (1862); **17**, 318 (1864).

[2] Interesting work was done by Selmi in 1844, but it had no appreciable effect on the development of scientific thought.

[3] Cf. Wolfgang Ostwald, "Grundriss der Kolloidchemie," 79 (1909).

ons; inks; roads, foundry cores, coke, asphalt; graphites, patines, zinc, phosphorus, sodium, and aluminum; contact sulphuric acid, hardened oils, etc.; beer, ale, and wine; cream, butter, cheese, and caseine products; cooking, washing, dyeing, printing; ore flotation, water purification; sewage disposal; smoke prevention; photography; wireless telegraphy; pharmacy; physiology. In other words, colloid chemistry is the chemistry of daily life.

ADSORPTION OF GASES AND VAPORS BY SOLIDS.

In an extremely subdivided phase the surface is very large relatively to the mass of the phase, and therefore the first step in the study of colloid chemistry is to discuss the properties of surfaces, beginning with the behavior of solids in contact with gases or vapors. All solids tend to adsorb, or condense upon their surfaces, any gases or vapors with which they are in contact. The amount of adsorption varies with the nature and physical state of the solid and with the nature of the gas; in other words, the adsorption is specific or selective. The amount of gas adsorbed is greater the higher the pressure and the lower the temperature. In Table I are given some data to illustrate these points. Hempel and Vater[4] used a particular commercial animal charcoal which they mixed to a stiff paste with ox-blood diluted tenfold with water and which they then charred at 600°. In Table II are some data by Dewar[5] with cocoanut charcoal. The volumes of gas adsorbed have been calculated back to standard conditions; in other words, to the volumes which the adsorbed gases would occupy at 0° and 760 mm. pressure. Thus at −185° and 760 mm.

TABLE I.

Cubic Centimeters of Gas adsorbed by 1 c.c. Synthetic 600° Charcoal; Volumes probably corrected to 0° and 760° mm.

	+20°	−78°	−185°		+20°
H_2	7.3	19.5	284.7	NH_3	197.0
N_2	21.0	107.4	632.2	H_2S	213.0
CO	26.8	139.4	697.0	Cl_2	304.5
O_2	25.4	122.4	....	SO_2	337.8
	+20°	−78°		+20°	−78°
CO_2	83.8	568.4	CH_4	41.7	174.3
NO	103.6	231.3	C_2H_6	119.1	275.5
N_2O	109.4	330.1	C_2H_4	139.2	360.7
Ar	12.6	92.6	C_2H_2	135.8	488.5

[4] *Zeit. Elektrochemie*, **18**, 724 (1912).
[5] *Proc. Roy. Soc.*, **74**, 124 (1904).

TABLE II.

Cubic Centimeters of Gas adsorbed by 1 c.c. Cocoanut Charcoal; Volumes corrected to 0° and 760 mm.

	0°	−185°		0°	−185°
He	2	15	CO	21	190
H_2	4	135	Ar	12	175
N_2	15	155	O_2	18	230

the actual volumes of gas adsorbed would be only 88/273, or approximately one-third of the values given in Table II. The difference between the two charcoals is noticeable at the higher temperatures and becomes very marked at −185°. Data for many other gases and vapors are to be found in papers by Hunter.[6]

As a first approximation, it is often stated that a gas or vapor is adsorbed more readily, the higher its boiling-point. Thus helium is taken up by charcoal much less than hydrogen, and hydrogen again is adsorbed to a less extent than nitrogen or oxygen. Carbon dioxide is adsorbed more readily than oxygen and less readily than ammonia, so that these six substances follow the empirical rule. Argon, however, is adsorbed less readily by charcoal than either oxygen or nitrogen, while carbon monoxide is adsorbed to a greater extent at 0° than either argon or oxygen, though this ought not to be so. Nitrous oxide is adsorbed less readily than ethylene and acetylene, which is not according to the boiling-points. Nearly three times as much hydrogen sulphide as carbon dioxide is adsorbed at +20°, though the boiling-point of the first, −73°, differs but little from the sublimation point of the second, −79°. Hydrogen sulphide is adsorbed more than ammonia, which is wrong, and chlorine is adsorbed much more strongly than ammonia, although the two boiling-points are practically identical. Cyanogen is adsorbed more than ammonia at 70° and less at 0°. In the case of vapors there is no relation between boiling-point and adsorption. Going from higher to lower boiling-points, we have the order: water, benzene, ethyl alcohol, carbon tetrachloride, methyl alcohol, chloroform, ether, and aldehyde. The order from greater to lesser adsorption is: aldehyde, methyl alcohol, ethyl alcohol, ether, benzene, water, chloroform, and carbon tetrachloride. The truth of the matter is that adsorption

[6] *Phil. Mag.* (4), **25**, 364 (1863); *Jour. Chem. Soc.*, **18**, 285 (1865); **20**, 160 (1867); **21**, 186 (1868); **23**, 73 (1870); **24**, 76 (1871); **25**, 649 (1872).

is specific and varies with the nature of the gas and of the adsorbing solid. It is fairly obvious what characteristics a charcoal should have in order to adsorb well; but this is unfortunately a military question and therefore cannot be discussed now.

The adsorption of gases by charcoal has been made use of by Tait and Dewar [7] as a means of getting a high vacuum. A bulb of air, 300 c.c. capacity, containing air at 15° and an initial pressure of 1.7 mm., was connected to a charcoal condenser containing five grammes of charcoal.[8] When the charcoal was cooled in liquid air, the pressure dropped to 0.000047 mm. Some of the digestive tablets taken by people after their meals consist largely of charcoal, and one of their functions is to adsorb gases in the stomach which would otherwise give rise to discomfort.

Since different gases are adsorbed in different amounts, the ratio of two gases in the charcoal will differ from the ratio in the gas phase and a fractional separation will be possible to some extent. Dewar [9] passed air at −185° over charcoal and obtained 98 per cent. nitrogen, while the adsorbed gas contained 55 per cent. oxygen. Above +100° the adsorbed oxygen reacts when the charcoal is heated and comes off as carbon monoxide and carbon dioxide. The data in regard to this are very unsatisfactory.[10] The general rule for mixtures of gases seems to be [11] that the more readily adsorbed gas displaces the other to some extent and is therefore adsorbed more relatively than one would have expected from experiments on the single gases. This is not universally true. Bergter [12] found that at pressures of 0.5 to 10 mm. oxygen is adsorbed 30 to 40 times as strongly as nitrogen, and that at these pressures the presence of oxygen increases the amount of nitrogen adsorbed. With readily condensible gases, it is not unusual to have one of the vapors increase the adsorption of the other.[13] A striking instance is with water and ammonia. It seems probable that the adsorbed water dissolves or adsorbs

[7] *Proc. Roy. Soc. Edin.*, **8**, 348, 628 (1874).

[8] Dewar, *Proc. Roy. Inst.*, **18**, 437, 756 (1906).

[9] *Proc. Roy. Soc.*, **74**, 126 (1904); *Proc. Roy. Inst.*, **18**, 184 (1906).

[10] Blumtritt, *Jour. prakt. Chem.*, **98**, 418 (1866); Baker, *Jour. Chem. Soc.*, **51**, 249 (1887); Rhead and Wheeler, *Ibid.*, **103**, 461, 1210 (1913); Manville, *Jour. Chim. phys.*, **5**, 297 (1907).

[11] Freundlich, "Kapillarchemie," 99 (1909).

[12] *Drude's Ann.*, **37**, 480 (1912).

[13] Hunter, *Jour. Chem. Soc.*, **23**, 73 (1870).

ammonia, thus increasing the amount of ammonia apparently held by the charcoal.

The adsorption of gases by charcoal has been studied extensively, because charcoal adsorbs so many gases and adsorbs them so strongly. Experiments have also been made with all sorts of other adsorbing agents—silica, alumina, glass, wool, rubber, celluloid, meerschaum, metals, soils, etc. The behavior of glass is important because of its use in the laboratory. Mülfarth [14] found that the adsorption decreased in the order: NH_3,SO_2,CO_2, N_2O,C_2H_2. Kundt and Warburg [15] found that a small amount of water is retained obstinately by glass even when the pressure is reduced practically to zero. In order to remove this water the glass must be heated. On the other hand, the film of water which usually covers the glass surfaces is due chiefly to alkali dissolved from the glass.[16] L. J. Briggs [17] showed that finely divided quartz adsorbs water vapor, though not to the same extent as amorphous silica. About 9 mg. water was adsorbed at 30° by 50 g. quartz having an estimated surface of 20,000 cm.^{2} when the vapor pressure was 26.1 mm., about 4.5 mg. when the vapor pressure was 19.6 mm. and about 0.5 mg. when the vapor pressure was 0.2 mm. Cohnstaedt [18] believes that the gas given off by aluminum electrodes in a Crookes tube is water vapor, and not hydrogen, as usually believed. He claims to prove that glass and aluminum surfaces will retain water even when heated to 500° or when dried over phosphorus pentoxide.

It is the presence of a water film of varying thickness on a glass or other vessel which makes it necessary to keep the moisture constant if accurate weighings are to be made. Professor Morley once said that it was a mistake to believe that it is a difficult matter to dry a gas. That is a very simple thing to do. The difficulty is to dry the vessel which holds the gas.

Drucker and Ullmann [19] showed that the adsorption of a vapor by the glass containing-vessel causes only a negligible error in vapor-density determinations with ether, alcohol, benzene, and

[14] *Drude's Ann.*, **3**, 328 (1900).

[15] Cf. Bunsen, *Pogg. Ann.*, **156**, 201 (1875); *Wied. Ann.*, **24**, 327 (1884).

[16] Warburg and Ihmori, *Wied. Ann.*, **27**, 481 (1886); Ihmori, *Ibid.*, **31**, 1006 (1887).

[17] *Jour. Phys. Chem.*, **9**, 617 (1905).

[18] *Drude's Ann.*, **38**, 223 (1912).

[19] *Zeit. phys. Chem.*, **74**, 567 (1910).

chloroform; but the error may amount to two per cent. with acetic acid at 80°. At higher temperatures the adsorption decreases and the error is correspondingly less. The adsorption of ammonia by solid ammonium hydrosulphide introduces a serious error in the equilibrium relations of ammonia and hydrogen sulphide.[20]

Platinum black may take up 100 volumes of hydrogen and palladium nearly up to 3000 volumes of hydrogen,[21] but it is not certain whether this hydrogen is all adsorbed or is partly dissolved. In gas analysis, palladium, heated at 100°, is used to remove hydrogen. This is purely a question of rate. Equilibrium is reached more rapidly at the higher temperature, though the palladium cannot take up so much hydrogen as at lower temperatures. Platinum black will take up more than 800 volumes of oxygen; but it seems certain that in this case some of the platinum has been oxidized.[22] Celluloid adsorbs carbon dioxide, and rubber apparently adsorbs it [24] as well as other gases, though it is possible that we have true solution in the case of rubber. Wool [25] adsorbs either hydrochloric acid gas or ammonia gas. Ramsay [26] considers that the nitrogen found in zinc is due to ammonia adsorbed from the air by the zinc.

If the film of adsorbed air on a small particle remains approximately of the same thickness, irrespective of the diameter of the particle, the ratio of air film to mass of particle will increase as the particle grows smaller. Cushman and Coggeshall [27] found that a rock powder which would pass through a 200-mesh sieve surged like a liquid. When poured into a vessel, it filled only 46 per cent. of the space, while coarser powder filled more. It is not surprising that the air-cushion round each particle makes the grains move over one another like a liquid. With a substance like carbon black, which adsorbs gases very markedly, as little as 5 per cent. of the apparent volume may be due to the carbon black,[28] and a liter of carbon black may contain 2.5 liters of air.[29]

[20] Magnusson, *Jour. Phys. Chem.*, **11**, 21 (1907).
[21] Paal and Gerum, *Ber. deutsch. chem. Ges.*, **41**, 805 (1908).
[22] Engler and Wöhler, *Zeit. anorg. Chem.*, **29**, 1 (1901).
[24] Lefebvre, *Jour. Chem. Soc.*, **105**, 328 (1914).
[25] Reychler, Van Bemmelen Gedenkboek, 55 (1910).
[26] Freundlich, "Kapillarchemie," 106 (1909).
[27] *Chem. News*, **92**, 80 (1905).
[28] *Jour. Franklin Inst.*, **174**, 672 (1912).
[29] Cabot, *Eighth Int. Congress Applied Chem.*, **12**, 18 (1912).
[29] Sabin, "Technology of Paint and Varnish," 201 (1917).

When indigo is reduced to a very fine powder [30] the single particles appear to be separated from one another by an envelope of air, so that the dry, solid powder occupies a space equal to that of a 20 per cent. paste of indigo containing the same amount of indigo. The presence of a film of air or vapor round a solid particle is shown in a striking way by the fact that it is quite a simple matter [31] to pass suspended phosphorus pentoxide through several wash-bottles in spite of its tremendously hygroscopic nature. Since the sulphur trioxide from the contact process can be caught in concentrated acid but not satisfactorily in water, we know that the concentrated acid displaces the gas film rapidly and fairly completely, while water does not; but we do not yet know what the reason for this is.

From experiments on the disruptive discharge through gases, Schuster [32] concluded that there was a condensed surface layer of gas having a high inductive capacity in contact with the solid electrode. Since this layer of adsorbed gas offers an increased resistance to the electrical discharge, it follows, from the theorem of Le Chatelier, that an electrical stress will tend to remove the film of adsorbed gas. This enables us to account for many apparently unrelated facts. Electrical waves tend to remove active oxygen and active hydrogen from an electrode and will therefore cut down the over-voltage.[33] Superposing an alternating current on a direct current also decreases the over-voltage,[34] making other reactions possible. The experiments of Margules [35] and of Ruer [36] on the dissolving of platinum find their explanation in the cutting down of the over-voltage.[37] With direct current there is oxidation to a higher and insoluble stage. With alternating current the over-voltage is decreased and little or none of the

[30] Willcox, *Jour. Soc. Dyers and Colourists*, **17**, 294 (1901).

[31] Engler and Wild, *Ber. deutsch. chem. Ges.*, **29**, 1929 (1896).

[32] *Phil. Mag.* (5), **29**, 197 (1890).

[33] Bennewitz, *Zeit. phys. Chem.*, **72**, 223 (1910); Rothmund, *Drude's Ann.*, **15**, 193 (1904).

[34] Archibald and von Wartenberg, *Zeit. Elektrochemie*, **17**, 812 (1911); Reitlinger, *Ibid.*, **20**, 261 (1914); Ghosh, *Jour. Am. Chem. Soc.*, **37**, 733 (1915); Stepanov, *Chem. Abstracts*, **10**, 2431 (1916).

[35] *Wied. Ann.*, **65**, 629; **66**, 540 (1898).

[36] *Zeit. phys. Chem.*, **44**, 81; *Zeit. Elektrochemie*, **9**, 235 (1903); **11**, 10, 661 (1905); Haber, *Zeit. anorg. Chem.*, **51**, 365 (1906).

[37] Zeitlinger, *Zeit. Elektrochemie*, **20**, 261 (1914).

insoluble compound is formed. The electrolytic detector, the crystal detector, and the coherer, as used in wireless telegraphy,[38] owe their action to the partial or complete elimination of an air film by means of an electrical stress. In connection with this it is interesting to note that Lenard[39] found that mercury wets platinum only when a current is flowing. At other times there is evidently an air film. It has been claimed by Allen[40] that the photo-electric fatigue of metals is due to a change in the surface film of gas or in the gas occluded in the metal (Hallwachs). It cannot be due to a chemical change such as oxidation; to a physical change such as roughening of the surface; to an electrical charge in the formation of an electrical double layer (Lenard); or to a disintegration of the metal due to the expulsion of electrons by light (Ramsay and Spencer). The difference in the results obtained by Allen and by Robinson[41] may be due to the fact that Allen worked at atmospheric pressure, while Robinson's measurements were made on electrodes in a high vacuum.

In cases of marked adsorption of gases it is interesting to determine what is the probable density of the adsorbed gas. Mitscherlich[42] calculated that when carbon dioxide at atmospheric pressure and 12° is adsorbed by boxwood charcoal the carbon dioxide occupies only one fifty-sixth of its original volume. Since this is a lesser volume than the same amount of carbon dioxide can occupy as gas at this temperature, it follows that some of it had been liquefied. Dewar[43] has calculated the apparent density of some gases adsorbed by cocoanut charcoal at low temperatures. The densities of the adsorbed gases are of the same order as those of the liquefied gases, and are greater in some cases. At higher temperatures the amount of adsorption would be smaller and the apparent condensation less.

It is to be noticed that the vapor pressure of a film of adsorbed gas in an apparently liquefied state stands in no relation to the vapor pressure of a mass of the liquefied gas. The phase rule generalization that the vapor pressure is constant for the system,

[38] Bancroft, *Jour. Phys. Chem.*, **20**, 503 (1916).

[39] *Wied. Ann.*, **30**, 212 (1887).

[40] *Phil. Mag.* (6), **20**, 564 (1910); cf. Lenard, *Drude's Ann.*, **8**, 196 (1902); **12**, 490 (1903).

[41] *Phil. Mag.* (6), **23**, 255 (1912).

[42] *Sitzungsber. Akad. Wiss. Berlin*, 1841, 376.

[43] *Proc. Roy. Inst.*, **18**, 438 (1906).

liquid and vapor at constant temperature, holds good explicitly only in case the disturbing effects due to gravity, electricity, distortion of the solid masses, and capillary tensions are eliminated. So soon as a liquid film becomes thin enough so that the liquid no longer has the property of matter in mass, the vapor pressure need not remain constant. When we have an adsorbed liquid or liquefied gas the vapor pressure will vary also with the nature of the adsorbing agent. The lowering of the vapor pressure is shown by the fact that oatmeal,[44] previously dried at a high temperature, has been used instead of sulphuric acid to produce the freezing of water under the receiver of an air-pump.

Since the amount of adsorption increases very rapidly with

TABLE III.

Molecular Heats of Adsorption and of Liquefaction of Gases.

Adsorbing agent	Gas	Adsorption Gram calories	Liquefaction Gram calories
Platinum	H_2	46200	
Palladium	H_2	18000	
Charcoal	NH_3	5900 – 8500	[5000]
Charcoal	CO_2	6800 – 7800	6250
Charcoal	N_2O	7100 – 7700	4400
Charcoal	SO_2	10000 – 10900	5600
Charcoal	HCl	9200 – 10200	[3600]
Charcoal	HBr	15200 – 15800	[4000]
Charcoal	HI	21000 – 23000	[4400]

falling temperature, there must be a very marked evolution of heat, and this is the case. In Table III are given some data by Favre.[45] The bracketed values are not his. All the heats of adsorption are higher than the corresponding heats of liquefaction. The abnormally high values for hydrogen in palladium and platinum cannot be due to dissociation into monatomic hydrogen, because that would be accompanied by an absorption of heat. They may be due in part to an oxidation of hydrogen. Masson[46] considers that the heat of adsorption of water vapor does not differ materially from the heat of liquefaction; but Dewar's data[47] confirm those of Favre, and we know also that

[44] Thomson, *Phil. Mag.* (4), **42**, 448 (1871).
[45] *Ann. Chim. Phys.* (5), **1**, 209 (1874).
[46] *Proc. Roy. Soc.*, **74**, 249 (1904).
[47] Dewar, *Proc. Roy. Inst.*, **18**, 183 (1905).

there is always a heat effect when porous solids are wetted by liquids.[48] This is probably due to an actual increase in the density of the adsorbed liquid. No one seems to have measured the change of the heat of adsorption with change of temperature.

The effect of traces of impurity on the adsorption is shown in some experiments by Berliner.[49] His purified palladium foil adsorbed about 860 volumes of hydrogen. If allowed to stand in the apparatus in a vacuum for an hour, it then adsorbed practically no hydrogen. If left for an hour or two in the air, the same thing happened. The disturbing factor is apparently a trace of grease, because water did not wet the soiled palladium. Similar results were obtained with platinum.

It is now advisable to consider the quantitative relation between pressures and adsorption.[50] If we plot the amounts of adsorbed gas as abscissæ and the pressures as ordinates, we get the so-called adsorption isotherm, a smooth curve concave to the pressure axis. If the gas is adsorbed strongly, the isotherm bends round at higher pressures to run nearly parallel with the pressure axis, because at these pressures a marked increase in pressure produces a relatively slight increase in adsorption. With gases, which are not adsorbed so readily, this latter portion of the curve is not reached at atmospheric pressure, which is as high as most people go. With ammonia in charcoal one can get the first type by working at 0° or lower, and the second type by working at 150°. If we plot the logarithms of the amounts of adsorbed gas against the logarithms of the pressures, we get a curve which approximates a straight line if the gas is not adsorbed too strongly. This shows that the data can be represented approximately by an equation of the form,

$$(x/m)^n = kp$$

where x is the amount of gas adsorbed and m the amount of

[48] Cf. Pouillet, *Ann. Chim. Phys.* (2), **20**, 141 (1822); Chappuis, *Wied. Ann.*, **19**, 21 (1883); Martini, *Phil. Mag.* (5), **47**, 329 (1899); **50**, 618 (1900); (6), **5**, 595 (1903); Parks, *Ibid* (6), **4**, 240 (1902); **5**, 517 (1903).

[49] *Wied. Ann.*, **35**, 803 (1888).

[50] Cf. Travers, *Proc. Roy. Soc.*, **78A**, 9 (1906); Davis, *Jour. Chem. Soc.*, **91**, 1066 (1907); Geddes, *Drude's Ann.*, **29**, 797 (1907); Boyle, *Jour. Phys. Chem.*, **12**, 404 (1908); *Phil. Mag.* (6), **17**, 377 (1909); McBain, *Ibid.*, **18**, 916 (1909); *Zeit. phys. Chem.*, **68**, 471 (1909); Homfray, *Ibid.*, **74**, 139, 687 (1910); Titoff, *Ibid.*, **74**, 641 (1910); Piutti and Maglia, *Gazz. chim. ital.*, **40 i**, 569 (1910).

adsorbing solid, while p is the pressure, and k and n are constants to be determined experimentally for each temperature.[51] The exponential factor n is so usually not an integer and its physical significance is unknown. In Table IV are some data by Geddes [52]

TABLE IV.

Adsorption of Carbon Dioxide by Charcoal.

Formula $x^{1.77}p = 0.0602$.

x = c.c. CO_2 adsorbed per c.c. charcoal.

p = pressure in mm. Hg. Temperature 31°.

p	x found	x calculated	p	x found	x calculated
41.5	1.7	1.7	453	6.5	6.4
120	2.9	3.1	534	7.1	7.1
194	4.0	4.0	602	7.6	7.6
276	4.7	4.9	678	8.3	8.2
340	5.4	5.5	698	8.6	8.3
405	5.9	6.0	73	8.9	8.4

on the adsorption of CO_2 by charcoal. The formula enables us to calculate the adsorption with a moderate degree of accuracy, but cannot possibly represent the facts for pressures at which the curve runs nearly parallel to the pressure axis.

The fact that we get a smooth curve when plotting pressure direct against adsorption shows that no definite compound is formed. The type of curve is characteristic of a continuous series of solid solutions or of an adsorption. The equilibrium is usually reached fairly rapidly, which is an argument against the existence of a solid solution, though by no means a conclusive one. More convincing is the fact that the amount of adsorption by charcoal varies with the structure.[53] While the experiments on the taking up of gases by charcoal show fairly conclusively that the surface phenomena are the important ones, there is always the possibility that a solid solution may also be formed to some extent. McBain [54] considers that over 13 per cent. of the hydrogen taken up by cocoanut charcoal at the temperature of liquid air is present as a solid solution.[55] On the other hand,

[51] For a slightly different formulation, see Williams, *Trans. Faraday Soc.*, **10**, 167 (1914).

[52] *Drude's Ann.*, **29**, 797 (1909).

[53] Piutti and Maglia, *Gazz. chim. ital.*, **40 i**, 569 (1910).

[54] *Phil. Mag.* (6), **18**, 916 (1909); *Zeit. phys. Chem.*, **68**, 471 (1909).

[55] Cf. Travers, *Proc. Roy. Soc.*, **78** A, 9 (1906).

Titoff [56] believes that the amount of hydrogen dissolved in the charcoal has been overestimated by McBain.[57] The truth of the matter is that we have no definite criterion which will enable us to distinguish accurately in all cases between solid solution and adsorption. In the case of gelatine and of cellulose it is quite possible that some water is actually dissolved. Until we know more about the subject it is safer to treat any doubtful case as chiefly one of adsorption.

On the other hand, the two special cases of metals and rubber with gases call for some special comment. Assuming the existence of pores in platinum or palladium foil, one can account for the selective diffusion of hydrogen by postulating adsorption in the pores and subsequent diffusion. At high temperatures the adsorption would be much less, and it is difficult to account for the increased rate of selective diffusion. It is simpler to account for the diffusion of hydrogen through platinum by postulating that some of the hydrogen actually dissolves in the platinum. In that case the solubility should be independent of the physical structure of the platinum. This seems to be true within narrow limits for platinum and within wide limits for palladium. It seems probable that platinum can dissolve several volumes of hydrogen at ordinary temperatures, and palladium nearly eight hundred volumes.[58] The bulk of the hundred volumes of hydrogen which are taken up by platinum black [59] must be adsorbed, and the same must be true of the nearly 3000 volumes taken up by colloidal platinum.[60] This is apparently the conclusion reached by Holt, Edgar, and Firth.[61] If platinum and palladium dissolve hydrogen to some extent, the passage of carbon monoxide through heated iron cannot be attributed to adsorption. At present it is not possible to say whether an iron carbonyl plays any part in the diffusion or not. In the case of platinum and oxygen

[56] *Zeit. phys. Chem.*, **74**, 641 (1910).

[57] For other discussions, see Masson, *Prov. Roy. Soc.*, **74**, 251 (1904); Davis, *Jour. Chem. Soc.*, **91**, 1066 (1907); Geddes, *Drude's Ann.*, **29**, 797 (1907); Wöhler, Pluddemann and Wöhler, *Zeit. phys. Chem.*, **62**, 670 (1908); Homfray, *Zeit. phys. Chem.*, **74**, 139, 687 (1910).

[58] Cf. Bose, *Zeit. phys. Chem.*, **34**, 708 (1900).

[59] Ramsay, Mond and Shields, *Ibid.*, **19**, 40 (1896); **25**, 657 (1898).

[60] Paal and Gerum, *Ber. deutsch. chem. Ges.*, **41**, 805 (1908).

[61] *Zeit. phys. Chem.*, **82**, 513 (1913).

Ramsay, Mond, and Shields [62] consider that most of the oxygen taken up forms $Pt(OH)_2$. They point out that Thomsen obtained an evolution of heat of 17,900 calories for the reaction $Pt + O = H_2O$, while they find 17,600 calories for the so-called adsorption of sixteen grammes of oxygen by platinum.

In view of the impermeability of rubber to water and its permeability to pyridine, it is hard to see how the permeability can be a question primarily of adsorption. I think that we must assume that carbon dioxide, pyridine, etc., actually dissolve in rubber.

While the equation $x/m = kp$ is a special case of the equation $(x/m)^n = kp$, where $n = 1$, and therefore may hold even in cases of adsorption, it is also the simplest case of Henry's law for the solubility of gases in liquids. Reychler [63] found that the amount of carbon dioxide taken up by blood charcoal was proportional to the partial pressure of the carbon dioxide in the vapor phase. The data are given in Table V. It does not seem probable that CO_2 dissolves in carbon, and I prefer to consider this a case of adsorption where the exponential factor happens to be unity. This view is confirmed by the fact that Geddes obtained very different relations for the adsorption of CO_2 by charcoal at 31° (Table IV).

TABLE V.

Adsorption of Carbon Dioxide by Blood Charcoal.

Formula $x/p = 0.00024$.
x = millimols CO_2 per gramme charcoal.
p = partial pressure in mm. Hg.
Temperature 20°

p	x	k	p	x	k
613.1	0.1461	0.00024	337.7	0.0855	0.00025
611.1	0.1424	0.00023	325.5	0.0808	0.00025
605	0.1320	0.00022	312.2	0.0706	0.00023
453.1	0.1014	0.00022	229	0.0560	0.00024
437.2	0.1086	0.00025	221.2	0.0523	0.00023
435.2	0.1063	0.00024	176	0.0452	0.00026
348.5	0.0844	0.00024	170.2	0.0451	0.00026
339	0.088	0.00026		mean	0.00024

Reychler also found that the amount of carbon dioxide taken up by rubber was proportional to the pressure over a narrow

[62] *Ibid.*, **25**, 684 (1898).
[63] "Van Bemmelen Gedenkboek," 55 (1910).

range of pressures. This may well be a case of solution of CO_2 in rubber.

CATALYTIC ACTION OF SOLIDS ON GASES.

The increased concentration at the surface of a solid will necessarily cause an increase in reaction velocity as a result of adsorption quite apart from any special catalytic action that the solid may exert. Nobody has ever compressed a mixture of oxyhydrogen gas so that it occupies the volume of liquid water, and consequently it is possible that the ignition of hydrogen and oxygen by spongy platinum may be due solely to the increased concentration. On the other hand, the fact that charcoal has very little effect in causing hydrogen and oxygen to combine indicates that some other factor is important in addition to increased surface concentration. In the case of SO_2 and O_2 Hempel [64] obtained a yield of 65 per cent. SO_3 without any catalytic agent by working at a pressure of thirty to forty atmospheres. Calvert [65] found that oxygen adsorbed by charcoal will burn ethyl alcohol to acetic acid, and ethylene to carbon dioxide and water. Damoiseau [66] showed that purified blood charcoal acted as a catalytic agent at 250° to 400°, causing the chlorination of ethyl chloride to hexachlorethane. Paal and Schwarz [67] have polymerized acetylene with platinum. The decomposition of carbon monoxide into carbon and carbon dioxide at nickel and cobalt surfaces [68] is another case in which it is possible, though not proved, that the reaction velocity depends primarily on the increase in surface concentration.

We can now consider the theory of cases in which special catalytic action occurs. Since we have adsorption from a gaseous mixture, we may also have selective adsorption of the reaction products, and this may cause one reaction to predominate at the expense of another. It is usually assumed that a catalytic agent cannot displace the equilibrium;[69] but this conclusion is neces-

[64] *Ber. deutsch. chem. Ges.*, **23**, 445 (1890).

[65] *Jour. Chem. Soc.*, **20**, 293 (1867).

[66] *Comptes rendus*, **73**, 60 (1876).

[67] *Ber deutsch. chem. Ges.*, **48**, 1195 (1915).

[68] Schenck and Zimmermann, *Ibid.*, **35**, 1231 (1903); Smits and Wolff, *Zeit. phys. Chem.*, **45**, 199 (1903).

[69] Van't Hoff, "Lectures on Theoretical Physical Chemistry," 215 (1898); Ostwald, *Zeit. Elektrochemie*, **7**, 998 (1901).

sarily true only when equilibrium is reached fairly rapidly in the gas phase. A solvent may accelerate a reaction and is therefore a catalytic agent. It may, and usually does, displace equilibrium, as in the case of nitrogen peroxide.[70] Hydrochloric acid is highly dissociated in water, but not in most solvents. If we have a reaction which takes place extremely slowly in the vapor phase and relatively rapidly in or at the surface of a solid catalytic agent, we may consider the adsorbing surface as equivalent to a solvent,[71] since we shall have the equilibrium in or at the surface, which corresponds to the surface, and which will not necessarily correspond with the theoretical equilibrium in the vapor phase. When the reaction products diffuse from the surface into the vapor phase they do not react by definition, and consequently we get in the vapor phase an apparent equilibrium corresponding to the surface conditions and which may vary markedly with different solid catalytic agents. Where two different reactions are possible, a given solid catalytic agent will increase the yield of the reaction products which are adsorbed the most strongly. Thus hydrogen is adsorbed by pulverulent nickel, platinum, or copper, and water vapor by pulverulent alumina.[72] As one might expect, alcohol is decomposed nearly quantitatively into acetaldehyde and hydrogen when passed over heated nickel or copper[73] and nearly quantitatively to ethylene and water when passed over heated alumina[74] or silica.[75] When titanium oxide is used as catalytic agent, both reactions take place simultaneously, and a yield of 84 per cent. C_2H_4 and 16 per cent. H_2 can be obtained under certain conditions. This should mean that titanium oxide adsorbs both water and hydrogen. This can be shown indirectly. When a mixture of alcohol and water vapor is passed over heated titanium oxide, the presence of the water vapor decreases the ethylene formation and there is an increased relative yield of hydrogen.[76] Conversely, there is an increased relative yield of ethylene if hydrogen is mixed with the alcohol vapor. If

[70] Cundall, *Jour. Chem. Soc.*, **59**, 1076 (1889); **67**, 794 (189?).

[71] Bancroft, *Jour. Phys. Chem.*, **21**, 588 (1917).

[72] Johnson, *Jour. Am. Chem. Soc.*, **34**, 911 (1912).

[73] Sabatier and Senderens, *Comptes rendus*, **136**, 738, 921, 936, 983 (1903).

[74] Ipatieff, *Ber. deutsch. chem. Ges.*, **34**, 3579 (1901); **35**, 1047, 1057 (1902); **36**, 1990, 2003, 2014, 2016 (1903).

[75] Sabatier and Senderens, *Comptes rendus*, **146**, 125 (1906).

[76] Engelder, *Jour. Phys. Chem.*, **21**, 676 (1917).

methane and hydrogen are heated with oxygen in presence of platinum or palladium, the hydrogen burns first,[77] whereas in borosilicate glass bulbs methane burns [78] before hydrogen.[79]

If a strongly adsorbed gas is added to a reacting mixture, it may cut down the adsorption of the reacting substances so much that the reaction comes practically to a standstill. Lunge and Harbeck [80] found that traces of carbon monoxide destroyed the catalytic action of platinum black on a mixture of hydrogen and ethylene. This poisoning of the catalytic agent, as it is called, is a very serious matter in many technical processes. If the reaction products are not removed sufficiently rapidly they will decrease the adsorption of the reacting substances and therefore retard the reaction. Sulphur trioxide [81] may have this effect in the contact sulphuric acid process.

Another set of reactions deserves mention here: the decomposition of arsenic hydride, antimony hydride, etc., where the reaction takes place chiefly at the surface of the containing vessel and not in the mass of the gas. To take a single case, the rate of decomposition of antimony, SbH_3 is accelerated by the presence of metallic antimony.[82] If we assume that antimony adsorbs antimony or tends to make antimony vapor condense upon it, the catalytic action follows at once. Lewis [83] has shown that the decomposition of silver oxide into silver and oxygen is accelerated by silver. At first sight this looks like the catalytic decomposition of one solid by another; but it seems impossible that the silver should act at a distance. It is probable, therefore, that we are really dealing with the decomposition of silver oxide vapor, in which case the reaction differs only in degree from the decomposition of stibnine. Taylor and Hulett [84] have shown that

[77] Henry, *Phil. Mag.*, **65**, 269 (1825); Hempel, *Ber. deutsch. chem. Ges.*, **12**, 1006 (1879).

[78] Bone, *Jour. Chem. Soc.*, **85**, 694 (1904).

[79] Bancroft, *Jour. Phys. Chem.*, **21**, 661 (1917).

[80] *Zeit. anorg. Chem.*, **16**, 50 (1898).

[81] Bodländer and Köppen, *Zeit. Elektrochemie*, **9**, 566 (1903); Berl, *Zeit. anorg. Chem.*, **44**, 267 (1905); Bodenstein, *Zeit. phys. Chem.*, **60**, 61 (1907).

[82] Stock and Guttmann, *Ber. deutsch. chem. Ges.*, **37**, 901; Bodenstein, 1361 (1907).

[83] *Zeit. phys. Chem.*, **52**, 310 (1905).

[84] *Jour. Phys. Chem.*, **17**, 568 (1913).

the decomposition of mercuric oxide is facilitated by finely divided platinum, ferric oxide, manganese dioxide, and cadmium oxide, but not by stannic oxide or alumina. While this is undoubtedly an adsorption phenomenon, the details are not sufficient to enable us to account satisfactorily for the results.

ADSORPTION OF GASES OR VAPORS BY LIQUIDS.

Since a gas or vapor may be adsorbed by a solid, one might expect to find selective adsorption by a liquid as well, and this proves to be the case.[85] Lord Rayleigh[86] found that impinging drops of water did not necessarily coalesce. If they were slightly electrified they coalesced readily, while stronger electrification kept them apart. A film of adsorbed air keeps the uncharged drops from coming into actual contact, and a slight electrification removes this film sufficiently to permit coalescence. Highly charged drops repel each other, this effect becoming noticeable for drops of 1 mm. radius when charged to 0.0031 volts.[87]

When the water drops from an oar on the recover, we often get what are known as rolling drops,[88] which depend on the presence of adsorbed air and which are also sensitive to the presence of electrified substances. Since soap-bubbles are hollow drops, we should expect them to behave in some ways like liquid drops, though not necessarily like the drops of a pure liquid. It is possible to knock two bubbles together with considerable force without causing them to coalesce,[89] because of the presence of adsorbed air films on the surfaces. If the bubbles are electrified slightly they coalesce readily without bursting.

If a vapor is adsorbed by a liquid it will condense to a liquid film at a temperature above that of the normal dew-point. Cantor[90] showed that this could be realized experimentally with water and mercury. Clark[91] has made similar experiments, but they are not of much value, because he used olive oil as one of the liquids, and olive oil is not a well-defined and reproducible liquid.

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[85] Bancroft, *Jour. Phys. Chem.*, **20**, 1 (1916).
[86] *Proc. Roy. Soc.*, **28**, 406 (1879); **29**, 71 (1879); **34**, 130 (1882).
[87] Nipper, *Science*, **34**, 442 (1911).
[88] Kaiser, *Wied. Ann.*, **53**, 681 (1894).
[89] Boys, *Phil. Mag.* (5), **25**, 409 (1888).
[90] *Wied. Ann.*, **56**, 492 (1895).
[91] *Proc. Am. Acad.*, **41**, 361 (1906).

ADSORPTION OF LIQUIDS BY SOLIDS.

Just as we have selective adsorption of a gas or a vapor by a solid so we get selective adsorption of a liquid by a solid. If a liquid is adsorbed at a solid surface, it forms a liquid film there, and we say that it wets the solid. If a liquid is not adsorbed by a solid it does not wet the latter. There has been a good deal of question whether the liquid meets the wall at a definite angle—the contact angle—or whether the contact angle is zero. Lord Rayleigh [92] states definitely that, in his opinion, the contact angle is zero. This must be true if we consider that the liquid is adsorbed by the solid. The reason that the rise of a liquid in a capillary tube is independent of the nature of the tube is because the rising liquid does not come in contact with the walls of the capillary tube at all.[93] We are really dealing with the rise in a liquid tube, and it consequently makes no difference what material is used to support the liquid tube. That this is the real explanation can be seen from the fact that concordant results are not obtained when a liquid is allowed to rise in a dry tube. To get good results it is important to immerse the tube in the liquid and then to raise it.[94]

For a liquid to wet a solid in the presence of air, the liquid must be adsorbed more strongly than the air and must displace it. Hoffmann [95] gives a number of details as to the slowness with which some liquids displace adsorbed air from certain solids. Lycopodium powder is distinctly difficult to wet. The floating of metallic powders or of pieces of metal on water is due to the slowness with which water wets them. The Cape Cod lighter consists of a porous stone set in a brass handle. When this is dipped into a can of kerosene the kerosene is sucked rapidly into the pores, displacing the air. The lighter is taken out, lighted, and placed under the logs of a wood fire. The adsorbed kerosene burns for about ten minutes, enabling one to do away with paper and even with kindlings. Solidified bromine [96] has been used for analytical purposes. It consists of siliceous earth satu-

[92] *Scientific Papers*, **3**, 393 (1902).

[93] Fayleigh, *Scientific Papers*, **3**, 421 (1902).

[94] For a discussion of the experiments of Bigelow and Hunter, see Bancroft, *Jour. Phys. Chem.*, **21**, 407 (1917).

[95] *Zeit. phys. Chem.*, **83**, 385 (1913).

[96] Brand, *Jour. Chem. Soc.*, **52**, 688 (1887); cf. Thorp, "Outlines of Industrial Chemistry," 251 (1916).

rated with bromine which can be driven out by heat. Of more technical importance is the adsorption of fused magnetite by chromite.[97] The straight magnetite arc flickers badly, but this can be overcome by mixing the magnetite with some more refractory material, such as chromite. The chromite remains solid and holds the melted magnetite like a sponge. In this way these arcs have been made steady and thereby suitable for industrial use.

The adsorption of a liquid film may introduce quite an error in the determination of the specific gravity of solids when these latter are in a finely divided state. As long ago as 1848, Rose[98] pointed out that platinum in the state of foil has a specific gravity between 21 and 22, while a value above 26 was found for platinum precipitated from the chloride by sodium carbonate and sugar. He explained that the solid is not weighed alone in water, but in conjunction with a film of condensed water. The loss experienced by the solid in water is therefore diminished and the apparent specific gravity increased.

It was Edward Lear who wrote about the Jumblies that went to sea in a sieve. We do not yet go to sea in a sieve ourselves, but we can carry water in one. If we take a fine-meshed metal sieve and oil the meshes, air can still pass readily through the holes; but water does not wet the wires, and consequently surface tension prevents it from passing through the holes.[99] We can carry water in such a sieve if we do not fill it too full; but an oiled sieve is not a perfect substitute for a pail. The principle, however, has received an important technical application in the shower-proofing of textile fabrics.[100] If the fibers of a closely woven fabric are coated with some water-repellent hydrocarbon or wax or with a water-repellent salt, the fabric will be porous to air, but will shed water up to a certain point. If the water is once forced through the pores, either by pressure or friction, the rain will afterward pass through at that point. This is why a tent will leak in a rain if one touches the canvas with a finger. Awnings on a boat usually leak where they rest on a wooden or iron support. There is always enough wind or vibration to be equivalent to the touching of the tent with the finger. For the same

[97] Steinmetz, "Radiation, Light, and Illumination," 110 (1909).
[98] *Pogg. Ann.*, **73**, 1 (1848); *Jour. Chem. Soc.*, **1**, 182 (1879).
[99] Chwolson, *Lehrbuch der Physik*, 1 iii, 613 (1907).
[100] Weber, *Jour. Soc. Dyers and Colourists*, **17**, 146 (1901).

reason a tent is apt to leak around the pole. The reverse case is to be seen in the ordinary water-wings. They are made of a fine-meshed fabric which is first thoroughly wetted, so that a film of water is formed in the pores. The strength of this reënforced water film is so great relatively that one can blow up the water-wings without the air escaping, and the water-wings will support a grown person without difficulty.

Since the adsorption of liquids by solids is selective, it follows that a given solid will adsorb one liquid more than a second liquid. Consequently the first liquid will displace the second from contact with the solid. No systematic study of this phenomenon seems to have been made, but we know that kerosene will displace water in contact with copper, and that water will displace kerosene in contact with quartz,[101] while alcohol will displace oil in contact with metal,[102] and linseed oil [103] will displace water in contact with white lead. The whole process of ore flotation depends on the fact that the ore adsorbs oil more strongly than does the gangue. According to these facts one should use a rag dipped in alcohol with which to wipe off a lamp, and it is for these reasons that we cover metal surfaces with vaseline or with a heavy oil to prevent rusting. In the kitchen people wet the moulds before putting in corn-starch or gelatine, and they butter the pans before making fudge, or grease the griddles before making flapjacks. Aluminum griddles do not need to be greased, because the air in the oxide film keeps the cakes from sticking. In making pottery, it is the practice to oil the dies when making dust-pressed ware.[104] Infusorial earth is excellent [105] for cleaning glass plates for photographic purposes. Even very greasy plates become clean very rapidly when rubbed with infusorial earth moistened with water. Some of the methods for removing grease spots from clothes depend on selective adsorption.[106] Actors use grease paints to prevent too marked adsorption.

There are almost no quantitative data on selective adsorption. Graham [107] made a few rough measurements on the selective

[101] Hofman, *Zeit. phys. Chem.*, **83**, 385 (1913).
[102] Pockels, *Wied. Ann.*, **67**, 669 (1899).
[103] Cruickshank Smith, "The Manufacture of Paint," 92 (1915).
[104] Simcoe and Smith, *Trans. Am. Ceramic Soc.*, **14**, 558, 567 (1912).
[105] Koller, "The Utilization of Waste Products," 310 (1915).
[106] Lake, *Jour. Phys. Chem.*, **20**, 761 (1916).
[107] *Jour. Chem. Soc.*, **20**, 275 (1867).

adsorption of liquids by palladium. A piece of foil was immersed in a liquid for an hour and afterward dried by pressure for a few seconds between folds of blotting-paper. One thousand parts of palladium foil were found to retain 1.18 parts of water, 5.5 of alcohol, 1.7 of ether, 0.54 of acetone, 4.5 of glycerine, 3.5 of benzene, 10.2 of castor oil, and 18.1 of oil of sweet almonds. Quite recently Mathers [108] has shown that lead adsorbs certain essential oils from aqueous solution.

Since the adsorption is selective, a vapor or liquid will be adsorbed more readily by one surface than by another. A striking application of this is to be found in the old daguerreotype process. The latent image is formed on a plate of silver coated with silver iodide, and it is developed by means of mercury vapor. The mercury condenses in the places which have been exposed to light. I have seen a patched cement floor on which moisture condensed so markedly on the weathered portion that it seemed as though a pipe had broken under the floor.

If the adsorption is very marked we may get intense strains.[109] Gelatine is adsorbed so strongly by glass that the gelatine film in drying will often tear loose fragments of glass. On the other hand, it does not adhere to plates of mica or calcite. With agar-agar the initial concentration appears to be important. Certain agar-agar jellies will adhere readily to glass, while others apparently do not. People have claimed that the substitution of agar-agar for gelatine in photographic plates would be impossible on a technical scale, because the agar-agar film would slip off if the plates were set vertically to dry. It is probable that this difficulty would be overcome if that were the only drawback.

The whole theory of adhesives depends in part on the fact that the cementing material adheres strongly to the two surfaces and hardens there. It is therefore possible that one agglutinant may be useful for a number of different materials, such as wood, glass, metal, ivory, etc., while others give good results only with special materials. Since the books give different recipes for cements for glass, cements for metals, cements for metals and glass, etc., the differences in adsorption are real ones, though nobody has ever made a careful study of agglutinants from this point of view.

[108] Private communication.

[109] Graham, *Jour. Chem. Soc.*, **17**, 320 (1864).

A good glue joint in wood will easily stand a strain of 6000 pounds per square inch. We are quite familiar with this, but we do not always realize that the tensile strength of liquid water is pretty high if a decrease in the cross-section can be prevented. Budgett [110] found a maximum breaking strength of about 87 pounds per square inch for steel end-gauges held together by a water film. On the assumption that the water occupied only one-tenth of the surface, this gives a tensile strength of nearly 900 pounds per square inch, or sixty atmospheres. As far back as 1850 Berthelot [111] filled a glass tube nearly full of liquid, removed the air, sealed the tube, heated the tube until it was entirely full of liquid, and allowed the whole thing to cool. The liquid continued to fill the tube until the volume was larger than it should be for the temperature by 1/420 in the case of water, 1/93 in the case of alcohol, and 1/50 in the case of ether. This indicates a breaking strain of about 50 atmospheres for water and over 100 atmospheres for alcohol and ether. Worthington [112] obtained 17 atmospheres for alcohol. Stefan [113] and Tumlirz [114] consider that the calculated internal pressure of a liquid is a measure of the theoretical tensile strength, and they obtain in this way a value for alcohol [115] of about 2000 atmospheres.

The adsorption of water vapor by gelatine presents some peculiarities. Working in Ostwald's laboratory, von Schroeder [116] found that gelatine contained over a thousand per cent. of water when immersed in liquid water and less than 400 per cent. when in saturated water vapor at the same temperature. From these and other experiments von Schroeder concluded that the vapor pressure of water in gelatine must be higher than that of pure water, because water distills from the gelatine to the vapor phase. The reason for this unexpected phenomenon is probably that gelatine has a cellular structure.[117] If a dry paper bag be placed in a space saturated with vapor water the paper will adsorb a certain

[110] *Proc. Roy. Soc.*, **82** A, 25 (1912).
[111] *Ann. Chim. Phys.* (3), **30**, 232 (1850).
[112] *Phil. Trans.*, **183** A, 355 (1892).
[113] *Wied. Ann.*, **29**, 685 (1896).
[114] *Sitzungsber. Akad. Wiss. Wien.* **100** II a, 837 (1900); **110** II a, 437 (1901).
[115] Cf. Hulett, *Zeit. phys. Chem.*, **42**, 353 (1903).
[116] *Zeit. phys. Chem.*, **45**, 109 (1903).
[117] Bancroft, *Jour. Phys. Chem.*, **16**, 395 (1912).

amount of water, but there will be little or no tendency for the bag to fill with liquid water. If a similar bag is immersed in liquid water the paper will take up water as before, but water will also pass into the bag and fill it. If the bag is then lifted into the vapor phase and if the bag is so constructed that the actual dripping is negligible, the water will distill from the curved surface of the bag to the plane surface in the containing vessel. The smaller the bag is the greater will be the curvature of the water surface and consequently the higher the vapor pressure. With the microscopic spaces to be assumed in solidified gelatine, the vapor pressure of the drops of water will be enough higher to counterbalance the differences of levels in von Schroeder's experiments.

While this explanation accounts for the phenomena, provided gelatine really has a cellular structure—a point which is not yet generally accepted—it is superfluous if the facts are not as stated. Wolff and Buchner [118] claim that the loss of water, when gelatine is placed in the vapor phase, is merely due to experimental error. They have certainly shown the possibility of error in von Schroeder's results, but they did no experiments involving as much error as one must assume if von Schroeder's data are worthless. The whole matter is therefore "up in the air" for the present.

There are other substances which seem to behave like gelatine, though no experiments like von Schroeder's have been tried. Schwalbe [119] states that cotton cellulose takes up 21 per cent. moisture in presence of saturated water vapor. Masson and Richards [120] find 17.7 per cent. adsorbed moisture when the vapor phase is 97 per cent. saturated. By extrapolation to 100 per cent. this might easily give about 21 per cent. moisture; but Masson and Richards incline to the view that the curve is asymptotic, in which case the value would be infinite, which seems absurd. Vignon [121] finds that one gram of cotton takes up about five grams of liquid water, while a fine-grained sponge will hold thirty grams of water per gram of sponge, and a coarse-grained sponge only about six grams. Leighton [122] states that

[118] *Zeit. phys. Chem.*, **89**, 271 (1915).
[119] "Die Chemie der Cellulose," 10 (1911).
[120] *Proc. Roy. Soc.*, **79** A, 421 (1905).
[121] *Comptes rendus*, **127**, 73 (1893).
[122] *Jour. Phys. Chem.*, **20**, 32 (1916).

absorbent cotton will hold four grams of water per gram of cotton when centrifuged at 4000 revolutions per minute. Some of this water is held in capillary spaces; some is adsorbed on the surface of the cotton; a part is probably dissolved in the cotton, and some may be held in cells. We have no satisfactory way of differentiating between these possibilities.

Dry caseine takes up about 1.25 grams of water per gram of caseine.[123] Infusorial earth[124] is able to take up more than double its weight of nitroglycerin without running.[125] Fibrous peat, fresh from the bog, may contain 90 per cent. of water, and Sphagnum moss may imbibe as much as two hundred times its own weight of water,[126] which is the reason that this moss is used largely in the trenches for dressing wounds. Attention might perhaps be called here to Meissner's experiments on the heat developed when powders are wetted by liquids.[127] He found that there was no appreciable difference in the heat evolved when the water was above or below 4°. His quantitative results were rather discouraging, however, because he found no apparent relation between the amounts of heat evolved and the amounts of powder taken, which must be the result of experimental error.

ADSORPTION OF SOLIDS BY SOLIDS.

Dried glue may be considered either as a solid or as a supercooled liquid. If we consider it as a solid, then the adsorption of gelatine by glass is a case of adsorption of a solid by a solid. It is more satisfactory to cite cases where both substances are unquestionably solid. If a metal is polished with rouge which is not kept sufficiently moist, the rouge adheres so firmly to the metal surface[128] that it cannot be removed without spoiling the polish. In blue powder we have grains of zinc coated with zinc oxide which adheres even when the zinc is melted. Aluminum and nickel are always coated with solid surface films which have marked effects on the properties of the metals. All patines on metals involve adsorption; otherwise they would come off readily.

[123] Van Slyke and Publow, "Science and Practice of Cheese-Making," 179 (1913).

[124] Koller, "Utilization of Water Products," 310 (1915).

[125] Kressmann, *Met. Chem. Eng.*, **14**, 372 (1916).

[126] "Percy's Metallurgy: Fuel," 208 (1875).

[127] *Wied. Ann.*, **29**, 114 (1886).

[128] Desch, "Metallographie," 210 (1914).

Passive iron owes its peculiar properties to the adsorption and stabilization of a higher oxide,[129] either FeO_2 or FeO_3. The latent image on photographic plates is due to an adsorption of silver by silver bromide.[130]

We get an apparent case of adsorption of a solid by a solid if we shake a moderately coarse powder with a much finer powder. Instead of the finer powder filling the voids in the space occupied by the coarse powder the former tends to coat the latter. [131] With a given mixture of thoria and tungsten Fink obtained a black powder which conducted electricity when the tungsten was finer than the thoria, and a white non-conducting powder when the reverse was the case. Briggs found that a mixture of 0.032 gram Prussian blue with 10 grams dolomite varied from deep blue to nearly white, depending on the relative sizes of the two powders. When 10 grams of dolomite was ground coarser than 40 mesh, 8 milligrams of lampblack produced a certain shade. When the dolomite was ground so that it all passed a 200-mesh sieve, 654 milligrams of lampblack, or over eighty times as much, were needed to produce approximately the same tint. This behavior of powders is of great importance when using inert fillers in mixed paints.[132]

If one strews lycopodium powder over the surface of water and then puts one's finger into the water, the lycopodium powder sticks to the finger and keeps it from being wetted.[133] A coarse powder kept in a bottle will fall to the bottom under the influence of gravity, while a very fine powder will stick to the walls of the bottle, discoloring them. It seems probable that the use of face powder is merely a special case of a very fine powder adhering to a curved surface. The retarding effect of gypsum on the rate of setting on Portland cement is probably due to the fact that the finer gypsum powder coats the coarser cement powder and acts to some extent as a protecting film.

In all of these cases the powders do not come in actual contact, but are separated by a film of air, which, however, holds them together, thus behaving like a liquid film. Traces of mois-

[129] Bennett and Burnham, *Jour. Phys. Chem.*, **21**, 107 (1917).
[130] Bancroft, *Ibid.*, **17**, 93 (1913).
[131] Fink, *Ibid.*, **21**, 32 (1917).
[132] Toch, "The Chemistry and Technology of Paints," 113, 138 (1916).
[133] Ehrenberg and Schultzer, *Zeit. Kolloidchemie*, **15**, 183 (1914).

ture will, of course, increase the adhesion, as with sugar on blueberries. Stoney [134] has shown that very fine powder in a metal dish becomes extremely mobile when the dish is hotter than the powder. The converse seems also to be true, that the powder is not mobile when it is hotter than the curved surface, because Tammann [135] finds that hot wood-charcoal powder adheres to a cold rod of glass or metal, but falls off when powder and rod are of the same temperature. Tammann was evidently working with particles coarse enough to fall off under the influence of gravity except when special conditions prevailed.

ADSORPTION OF LIQUIDS BY LIQUIDS.

The spreading of one liquid over another is usually considered to depend on the relative surface tensions, but this is not a very satisfactory way of looking at things.[136] The simplest way is to treat it as a case of adsorption. If oil is adsorbed by water it wets the water and spreads over the surface. The adsorbed layer may vary from 2 to 200 [137] $\mu\mu$ with different oils.[138] At greater thicknesses the oil may tear loose from the oiled surface of the water, drawing up into drops under the influence of surface tension. At still greater thicknesses the drops coalesce to form a liquid layer having the properties of matter in mass. If the oil is not adsorbed by water there is no spreading. This case seems to have been realized by Hardy.[139]

ADSORPTION OF SOLIDS BY LIQUIDS.

A solid which is wetted by a liquid adheres to that liquid. With two liquids and one solid we shall get selective adsorption of the solid, and this leads to some interesting results which have been studied in detail by Hofmann.[140] If finely divided red lead is shaken with water and benzene or chloroform, the red lead adheres to the surface of the benzene or chloroform, making a practically continuous coating around the organic liquid, provided proper relative amounts of red lead and organic liquid are taken.

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[134] *Phil. Mag.* (5), **4**, 443 (1877).
[135] *Drude's Ann.*, **18**, 856 (1905).
[136] Rayleigh, *Scientific Papers*, **3**, 354, 413, 416 (1902).
[137] μ = micron = thousandth millimeter; $\mu\mu$ = millionth millimeter.
[138] Hardy, *Proc. Roy. Soc.*, **86** A, 612 (1912).
[139] *Proc. Roy. Soc.*, **86** A, 632 (1912).
[140] *Zeit. phys. Chem.*, **83**, 385 (1913).

The theory of the phenomenon has been given by Des Coudres.[141] If water displaces benzene or chloroform from the surface of a given solid, the solid will tend to stay in the water phase; if benzene or chloroform displaces water, the solid tends to stay in the benzene or chloroform phase; if neither liquid displaces the other completely, the solid will tend to pass into the dineric [142] interface. The solid particles stay in the interface or in the upper liquid layer only when they are fairly fine. In Table VI are given some of Hofmann's results. The letter *w* means that

TABLE VI.

	Water and ether	Chloroform	Butyl alcohol	Benzene	Kerosene	Amyl alcohol	Paraffin oil
$CaSO_4$	*w*	*w*	*w*	*w*	*w*	*w*	*w*
SnO_2	*w(s)*	*ws*	*ws*	*s(w)*	*s(w)*	*sw–*	*sw*
$Al(OH)_3$	*w(s)*	*ws*	*ws*	*s*	*s(w?)*	*sw*	*s(w)*
SnS	*ws*	*ws*	*ws*	*s(w)*	*s(w)*	*s*	*ws*
$BaSO_4$	*ws*	*ws*	*ws*	*s*	*s*	*s(w?)*	*s(w?)*
ZnS	*w(s)*	*ws*	*ws*	*s*	*s(w?)*	*s*	*s(w?)*
ZnO	*ws*	*ws*	*s(w)*	*s*	*s*	*s*	*s*
$CaCO_3$	*ws*	*ws*	*s*	*s*	*s*	*s*	*s*
$Mg(OH)_2$	*s(w?)*	*ws*	*s*	*s*	*s*	*s(w)*	*sw*
Al	*sw*	*s(w)*	*s(w)*	*s*	*s*	*s(w)*	*s*
$BaCO_3$	*ws*	*ws*	*s*	*s*	*s*	*sw*	*s*
CuS	*ws*	*s(w)*	*s*	*s*	*s*	*s*	*s*
$PbCrO_4$	*ws*	*s(w?)*	*s*	*s*	*s*	*s*	*s*
Cu_2O ?	*ws*	*s*	*s*	*s*	*s*	*s*	*s*
MoS_2	*s(w?)*	*s*	*s*	*s*	*s*	*s*	*s*
PbS	*ws*	*s*	*s*	*s*	*s*	*s*	*s*
Fe_3O_4	*ws*	*s*	*s*	*s*	*s*	*s*	*s*
$BaCrO_4$	*ws*	*s*	*s*	*s*	*s*	*s*	*s*
Pb_3O_4	*sw*	*s*	*s*	*s*	*s*	*s*	*s*
C	*sw*	*s*	*s*	*s*	*s*	*s*	*s*
PbI_2	*s*	*s*	*os*	*s*	*s*	*os*	*s*
HgS	*s*	*s*	*s*	*s*	*s*	*s*	*s*
HgO	*s*	*s*	*s*	*s*	*s*	*s*	*s*
HgI_2	*s*	*s*	*s*	*s*	*s*	*o*	*os*
AgI	*s*	*s*	*o*	*s*	*s*	*o*	*os*

the solid goes nearly completed into the water phase, while *o* denotes that it goes almost completely into the organic liquid, and *s* that the powder collects nearly quantitatively in the interface. Two letters, such as *sw*, means that the powder goes partly into the interface and somewhat less into the water phase; the use of parentheses, *s(w)* or *s(o)*, signifies that there is a good deal more powder in the interface than in the bracketed phase. Ben-

[141] *Arch. Entwicklungsmechanik*, **7**, 325 (1898).

[142] Dineric means "two-liquid."

zene and xylene behave alike, so only one is given. In these experiments the powder was placed in water and then shaken with the organic liquid.

Similar results were obtained by Reinders [143] with colloidal solutions. Isobutyl alcohol was added to a colloidal gold solution obtained by reducing gold chloride with carbon monoxide. When the two liquids are shaken, the gold forms a thin film at the interface. This film is violet-blue to blue-green by transmitted light and golden by reflected light. A thin film forms between the isobutyl alcohol and the glass, and the gold concentrates in the dineric interface thus formed, making the alcohol appear uniformly gold-plated. With ether the gold film rises high above the level of the two liquids. With carbon bisulphide the adherent film of gold appears blue. When the carbon bisulphide is broken into drops by shaking, each drop appears blue. When a blue gold was obtained by reducing gold chloride with phosphorus dissolved in ether, the gold went into the dineric interface. When a brownish-red gold was obtained in this way, it remained in the water phase and showed no tendency to pass into the interface. This difference is undoubtedly due to an adsorption of something at the surface of the gold, because Reinders found that 0.005 per cent. gum arabic prevents colloidal gold from passing into the ether-water interphase. With carbon tetrachloride, carbon bisulphide, and benzene, the gold goes into the interface as before, but the gum arabic prevents its changing from red to blue.

Colloidal arsenic sulphide goes into the dineric interface with amyl alcohol or isobutyl alcohol, but stays in the water phase when carbon tetrachloride, benzene, or ether is the second liquid. India ink goes completely into the interface with amyl alcohol, carbon tetrachloride, or benzene; it goes partly into the interface with isobutyl alcohol, and stays entirely in the water phase when ether is the second liquid. When crystallized copper eosinate is placed in water and shaken with ether it goes entirely into the interface,[144] forming a film which resembles the purple skin of a grape by reason of the steel-blue color of the crystals.

An interesting experiment is to shake copper powder or aluminum powder with kerosene and water. The metallic powder goes into the kerosene and into the interface, producing an effect

[143] *Zeit. Kolloidchemie*, **13**, 235 (1913).
[144] Gilbert, *Jour. Phys. Chem.*, **18**, 602 (1914).

of molten copper or molten aluminum, as the case may be. When the bottle is allowed to stand after having been shaken, the metallic powder in the interface creeps up the side of the bottle above the surface of the liquid, rising higher if a little alcohol has been added. I have seen a metallic film rise two or three inches above the surface of the upper liquid phase. If too much copper or aluminum be added the kerosene cannot hold it all up, and a portion falls to the bottom, carrying drops of kerosene with it. The aluminum and copper powders on the market are coated with stearin, but this helps the experiment, though not essential to it.

White lead passes from water into linseed oil,[145] and this is made use of in preparing pulp-ground lead.[146] Zinc oxide, on the other hand, stays in the water phase. The Elmore bulk-oil process of ore flotation depends on the fact that some sulphide ores can be shaken out of the water phase by means of suitable oils, while the gangue remains in the water phase.

The readiness with which solid films form over the surface of mercury is well known to everybody. They are due to the adsorption of certain compounds of mercury or of baser metals. The substances causing the "flouring" of mercury are soluble in cyanide solution.

In this paper there has been given a discussion of: adsorption of gases and vapors by solids; catalytic action of solids on gases; adsorption of gases and vapors by liquids; adsorption of liquids by solids; adsorption of solids by solids; adsorption of liquids by liquids; adsorption of solids by liquids.

CORNELL UNIVERSITY.

Calorized Iron as an Element for Thermocouples. O. L. KOWALKE. (*Proceedings of the American Electrochemical Society*, October 3–6, 1917.)—There are available several thermocouples with iron as one of the elements which have high electromotive forces and are fairly constant, but have the disadvantage that the iron element oxidizes rapidly above 500° C. If iron could be protected from oxidation by some sort of a coating which would not greatly change the electromotive force, its usefulness as an element for thermocouples would be greatly extended. It has been shown

[145] J. Cruickshank Smith, "The Manufacture of Paint," 92 (1915).
[146] Holley, "Lead and Zinc Pigments," 71 (1909).

by W. E. Rudder that "calorizing" iron, which consists in producing a rich aluminum alloy upon the surface of the metal, practically prevents oxidation below 1000° C.

The author has compared the thermo-electromotive forces of couples of "calorized" iron-constantan with that of uncalorized iron-constantan. A sample of calorized iron wire from the General Electric Company gave the same thermo-electric potentials as uncalorized iron up to 1000° C. on repeated calibrations. A sample from the Brown Instrument Company gave slightly different potentials until heat-treated at 800° C., after which it gave similar results to other calorized wire. The author concludes that a heavy wire, lightly calorized, gives as constant results as uncalorized iron and has a much longer life.

The Expansion and Contraction of Concrete and Concrete Roads. A. T. GOLDBECK and F. H. JACKSON, JR. (*U. S. Department of Agriculture,* Bulletin No. 532, October 13, 1917.)—Observation of concrete roads shows that most of the irregularities of wear make their initial appearance at expansion joints and at transverse and longitudinal cracks. Soon after a crack is formed traffic begins to batter down the edges, and unless immediate and effective maintenance measures are adopted, each succeeding vhicle will act with greater destructive effect. Under such conditions and without proper maintenance, little time elapses before depressions are formed in the road surface which lessen the life of the road and render it decidedly unpleasant to the fast-moving traffic generally carried by concrete roads. Improperly maintained expansion joints wear in a manner similar to cracks, and the cost of their maintenance is dependent upon their frequence.

Cracks result when the tensile strength of the concrete has been exceeded, or compression cracks may be caused in rare instances by excessive expansion without proper provision for such a movement. Tension may occur in a concrete pavement as the result of settlement or upheaval, in which case the pavement is stressed as a slab, and, if overstressed, will crack on the tension side. Most transverse cracks, however, are caused by contraction due to decrease in temperature and drying out of water from the concrete. When the drainage is good and the sub-base not wet, the temperature effects seem to be most important. In very dry climates, shrinkage due to drying must be added to contraction due to fall in temperature. Temperature at time of construction of road should be considered in designing joints. Cold-weather construction requires a full allowance for temperature expansion, and, on wet sub-bases, for moisture expansion also. Hot-weather construction theoretically requires no joints at all, even on wet sub-bases, as the temperature contraction exceeds the moisture expansion. However, the difficulty of keeping the cracks clear probably renders joints inoperative.

THE ELECTRON THEORY.*

BY

WILLIAM ALBERT NOYES, Ph.D., LL.D.,

Director of the Chemical Laboratory, University of Illinois.

It is only twenty years since Prof. J. J. Thomson first characterized accurately those atoms of negative electricity which we call electrons, but, as with most great discoveries, many lines of work and of thought, reaching back for more than a century, culminated in this discovery. It seems worth while to go back and pick up some of these threads and look at their relations.

On August 1, 1774, Priestley discovered oxygen. He called it dephlogistigated air, and explained its properties on the basis of the old theory of phlogiston. Lavoisier, in Paris, when he learned of this discovery, repeated the experiments and soon came to a clear view of the important part which the element plays in nature. He considered that compounds of oxygen with the non-metallic elements are acids and that the compounds with metallic elements are bases. These acid oxides and basic oxides, in turn, combine to form salts. The point in which we are interested is the notion that the acid oxides and basic oxides are binary compounds, and that salts are also binary compounds of a second order. About 1790, according to a tradition which is questioned, some frogs' legs which had been purchased for an invalid wife of the Italian physician, Galvani, were hung on brass hooks attached to an iron railing. One of Galvani's pupils noted a peculiar twitching of the frogs' legs and called Galvani's attention to it. Thus began the discovery and study of current electricity. I have found in an old chemistry this cut (Fig. 1) to illustrate Galvani's experiments. When the pieces of copper and zinc are brought into contact the current flows and the frogs' legs twitch into the second position.

Soon after, Volta, in Paris, invented the voltaic pile, by means of which much stronger currents could be obtained. This

* Abstract of a paper presented at the meeting of the Section of Physics and Chemistry held Thursday, April 12, 1917.

figure (Fig. 2), taken from an old chemistry published in 1846, shows one of these early galvanic batteries. Sir Humphry Davy used one of these batteries in London, about 1804, when he made his great discovery of the decomposition of potash and soda by the electric current. This discovery attracted his attention to the very intimate connection between electricity and chemical action, and led him to the proposal of the old electrochemical theory. This theory was further developed by Berzelius, and it dominated the minds of chemists for half a century.

According to this theory, the atoms of the elements have two poles, one positive and one negative, and each element is positive or negative, according to the relative amounts of the two charges. When two elements combine, the discharge be-

FIG. 1.

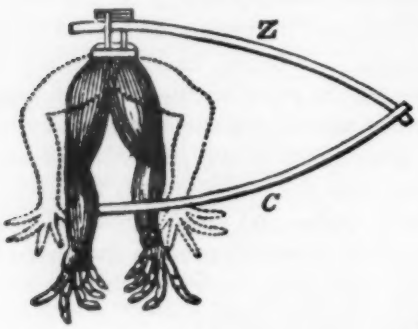
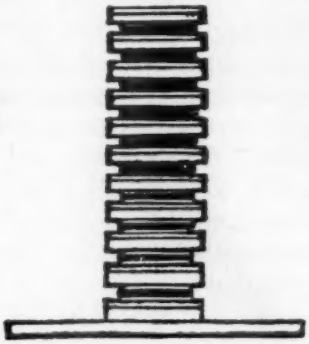


FIG. 2.



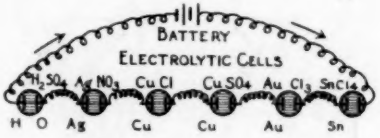
tween the positive pole of one and the negative pole of the other causes an evolution of heat. The resulting compound may still be positive, as in the case of a metal united with oxygen, or negative, as, for instance, the acid oxides. The union of the positive oxide with a negative oxide gives a salt. The intimate relation between the theory and Lavoisier's ideas about oxides and salts is apparent.

In 1833 Faraday discovered a method of measuring an electrical current by determining the quantities of hydrogen and oxygen liberated by passing the current through dilute sulphuric acid. He soon found that if the same current is passed through two electrolytes, as through dilute sulphuric acid and through a solution of copper sulphate in successive cells, the amounts of the elements liberated in the two cells will be in proportion to

the chemical equivalents of the elements. Thus in the series of cells shown in Fig. 3, when one gramme (in round numbers) of hydrogen has been liberated in the first cell, 108 grammes of silver will have been deposited in the second, 63.6 grammes of copper in the third, 31.8 grammes of copper in the fourth, 65.7 grammes of gold in the fifth, and 29.5 grammes of tin in the sixth.

I do not think that Faraday grasped the full significance of this wonderful law which bears his name. It points very clearly to a definite unit quantity of electricity which is directly connected with those primary units of matter which we call atoms. It is not a unit of energy, since the energy absorbed in the decomposition of the different electrolytes is not the same. Helmholtz stated the logical inference from the law very clearly in his Faraday lecture in 1881. He said, "If we accept the hypothesis that elementary substances are composed of atoms, we cannot avoid the conclusion that electricity, positive as well as

FIG. 3.

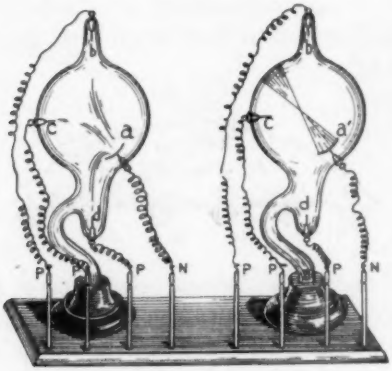


negative, is divided into definite elementary portions, which behave like atoms of electricity." This idea is very different from that in the theory of Berzelius, who considered that differences in affinity were caused by differences in the quantity of electricity in different atoms.

The next advance seems rather a step backward than forward, as it consisted in the overthrow and complete abandonment of the old electrochemical theory. In that theory chlorine was always negative and hydrogen was always positive in their compounds. But Dumas showed that three derivatives of acetic acid could be prepared in which one, two, or three atoms of the positive hydrogen could be replaced by one, two, or three atoms of the negative chlorine, and yet the resulting compounds were monobasic acids resembling acetic acid in their salts and in their decompositions. In his attempts to explain these and other compounds on the basis of the electrochemical theory, Berzelius found himself more and more in conflict with well-established

facts of organic chemistry, and, in spite of his tremendous authority as one of the leading chemists of his time, the chemical world gradually abandoned the dualistic point of view and accepted a unitary conception of chemical compounds. Then, beginning in the fifties, there came the period of the rapid development of the theories of valence and of structural organic chemistry. During this period, which lasts, with very little change, to the present time, the attempt to connect the forces which hold the atoms in combination with electrical forces in any definite way was almost completely abandoned. It is true that the terms "positive" and "negative" have been frequently used throughout the period, but they have been used in a wholly vague and

FIG. 4.

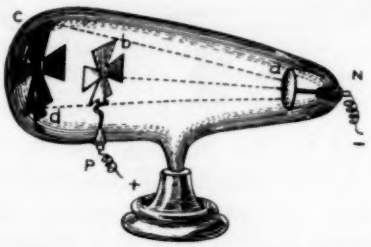


indefinite manner, with no real thought of electrical properties in the atoms or groups to which they are applied.

As so often happens, the beginning of a return to an electrical theory of combination came from the study of phenomena in a different and, as it seemed at the time, wholly unrelated field. During the late seventies, Crookes busied himself with the study of electrical discharges through highly rarefied gases. The phenomena which he discovered were so strange and startling that he spoke freely of a "fourth state" of matter. The physicists and chemists of the time were disposed to look on the expression as somewhat sensational, but the event has shown that he was nearer right than his critics. The phenomena of most interest to us are those of the discharge from the cathode, or

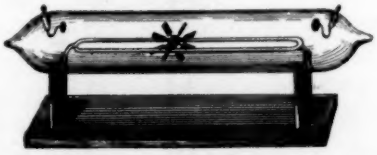
negative pole, through a tube in which the pressure of the residual gas has been reduced to one-millionth of an atmosphere. Under such conditions rays are shot out in straight lines perpendicular to the surface of the cathode, and when they impinge on the glass opposite they produce a beautiful green fluorescence and give rise to the X-rays, though those rays were not discovered till some fifteen years later. Crookes showed that this "radiant

FIG. 5.



matter," as he called it almost with the vision of a prophet, travels straight across the tube, irrespective of the location of the anode. Thus in the bulb containing rarefied air, shown at the left in the figure (Fig. 4), the current from an induction coil will pass in a curved path from the negative pole *a* to any one of the positive poles, *b*, *c*, or *d*, to which the positive pole of the coil is connected. When the pressure within the bulb is reduced to a millionth of an atmosphere or less, the cathode rays are shot

FIG. 6.



out at right angles to the surface of the negative pole and impinge on the glass opposite, irrespective of the attachment of the positive pole of the coil to the top, bottom, or side of the bulb. This effect is shown at the right of the figure. Crookes also showed that an opaque object in the path of the rays casts a shadow, as shown in Fig. 5. By a very ingenious apparatus he caused the stream of "radiant matter" (electrons) to drive a little windmill (Fig. 6). When a magnet is brought near the

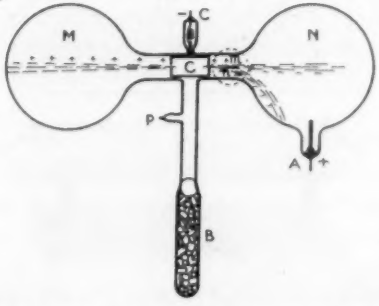
tube the rays are deflected in such a manner as to show that the rays consist of negative, charged particles (Fig. 7).

By means of this apparatus (Fig. 8), which has been kindly loaned by my friend, Professor Knipp, of the University of Illinois, I can show you the stream of electrons sent out by the cathode, *C*. The bulb, *B*, is filled with charcoal. When this is

FIG. 7.

immersed in liquid air the charcoal absorbs nearly all of the minute quantity of air which has been left in the apparatus, leaving a very high vacuum, which readily allows the passage of the cathode rays across the bulb, *N*. When I place this horseshoe magnet over the tube near the cathode the rays are bent downward, as you see. When the poles of the magnet are reversed, the rays are bent upward. The cathode is perforated and luminous; positive rays, which are called canal rays, are sent

FIG. 8.



across the bulb, *M*. You see that these positive rays are not deflected by the magnet. We shall come back to these later.

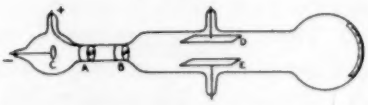
When the cathode rays strike the glass the X-rays discovered by Röntgen about 1890 are produced. In one place in his paper, published in *Chemical News* in 1879, Crookes speaks of this "radiant matter" shot from the cathode as belonging to the borderland between matter and energy. This seems almost

a prophecy of the doctrine of modern physicists that the mass of an electron is dependent on its velocity. Indeed, some physicists seem to say that the *whole* of the mass is due to the velocity, though I confess to some difficulty in understanding what is meant by such a statement. Crookes also predicted that some of the most important discoveries of the future would be made in connection with the study of "radiant matter"—a prediction which has been fully verified.

In 1887 Arrhenius published his classical paper on electrolytic dissociation. This laid the foundation for a new electrochemistry which has avoided many of the difficulties of the older theory and which furnishes the only rational means we have for the study of many of the properties of solutions of electrolytes. It is now clear that in such solutions electrolytes separate more or less completely into atoms or groups bearing positive or negative charges.

In 1897 Prof. J. J. Thomson took up again the study of the

FIG. 9.



cathode rays in the Crookes tubes. By means of the apparatus shown in Fig. 9 he showed that when static charges of opposite sign are applied to the plates *D* and *E*, the cathode rays passing through the narrow slits in *A* and *B* are attracted toward the positive plate, and this can be shown and measured by the motion of the spot of light falling on the scale at the end of the bulb. He then devised a very ingenious experiment in which he deflected the cathode rays into an insulated hollow vessel by an electromagnet. Knowing the capacity of the vessel, he could determine the quantity of electricity carried into it by the electrons in a given time. He then arranged to have the electrons fall on a thermocouple of known heat capacity, and determined the energy developed on stopping them. From the data obtained he calculated that the velocity of the particles was of the order of ten thousand miles a second, or even as high as one-tenth the velocity of light. The quantity of electricity carried by the particles was found to be very considerable in proportion to the heat

energy shown by the thermocouple. These facts seemed to allow for only two alternatives: either the mass of the particles is extremely small, or each particle must carry an enormous charge of electricity. Further experiments confirmed the choice of the first of these possibilities, and physicists are generally agreed that the mass of the electron is about one eighteen-hundredth part of the mass of a hydrogen atom. Physicists are not altogether agreed, however, as to whether this electromagnetic mass is the same in nature as the mass of an atom, which may be measured by reference to the force of gravity. If it is affected by gravity, an electron having a velocity of 10,000 kilometres a second would fall toward the earth possibly two millimetres in flying 800 kilometres, say as far as Cleveland. The difficulty of preparing a straight, evacuated tube of that length is evidently rather great, and we shall probably have to wait some time for experimental evidence on this point. The question has become one of unusual speculative interest in the light of the discussion by J. J. Thomson and the measurements of Kaufmann and Bucherer, which seem to show that the mass of the electron is wholly dependent on the velocity with which it moves.

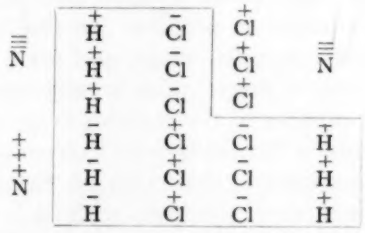
In the light of Thomson's experiments, we may now say that Crookes's " radiant matter " consists, in reality, of atoms of negative electricity. Professor Thomson called these atoms corpuscles, but they are now universally known as electrons. A knowledge of the properties of these new atoms has given us quite a new conception of the nature of a current of electricity in metallic conductors.

It has become clear that atoms of the elements contain electrons, and that metals allow these electrons to pass readily from one atom to another in a regular flow which furnishes the current of electricity in metallic conductors. In electrolytic conduction, on the other hand, electrons are associated with the negative ions, and these pass slowly through the liquid in one direction, while groups or atoms which have lost electrons and which have thereby become positive pass through the solution, usually at a different rate, in the opposite direction. In the wire the current consists in the flow of electrons; in the electrolyte it consists in the flow of two sets of ions in opposite directions.

My own interest in the chemical side of the electron theory arose from an accident. Some twenty years or so ago I had oc-

casion to perform the old Hofmann experiment with the use of a tube such as I hold in my hand. The tube is filled with chlorine, and when a solution of ammonia is added this chlorine should combine with an equal volume of hydrogen and liberate the nitrogen with which the hydrogen was combined. As ammonia is a compound containing one volume of nitrogen gas combined with three volumes of hydrogen, when water is allowed to enter, as you see it is doing, the tube should be left, at the end of the experiment, one-third full of nitrogen. I happened to use, on the occasion referred to, a dilute solution of ammonia and a smaller amount than usual. At the end of the experiment the tube contained one-sixth of its volume of nitrogen, as you see. I explained the result to the class as best I could, and tucked the matter away in my mind as something that would bear looking into. Several years later, in 1901, I had to find thesis subjects for a number of seniors at the Rose Polytechnic, and remembered the failure in the lecture experiment as a suitable topic. We found that when a solution of ammonia acts on chlorine, nitrogen trichloride (NCl_3) is formed. I explained the action at the time by the following diagram:

DIAGRAM 1.



Professor Bray has recently pointed out that a ninth-order reaction, such as is implied in this diagram, is, to say the least, highly improbable, but the suggestion that atoms may retain a positive or negative character in reactions which are not usually considered ionic has met with increasing favor. Van't Hoff [1] had made a somewhat similar suggestion about another reaction in 1895, and Professor Stieglitz published a note, shortly after the appearance of the paper by Lyons and myself, saying that he had presented the same idea some time before at the University

[1] *Z. physik. Chem.*, **16**, 411 (1895).

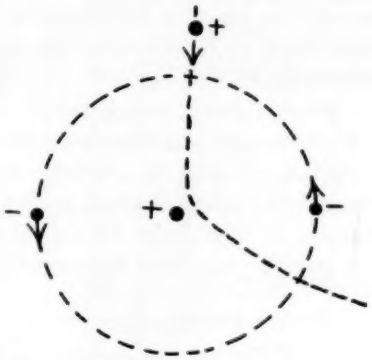
of Chicago. Neither of us, at the time, thought of any connection between these facts and the electron theory. Three years later Professor Abegg, of Breslau, published a remarkable paper in which he developed the idea of the electrical polarity of the atoms in considerable detail, and proposed his theory of normal valences and of contra valences, the sum of the two kinds of valences for any given atom being eight. Thus a nitrogen atom may develop toward hydrogen three negative, normal valences, or toward oxygen it may assume five, positive, contra valences. In this paper Abegg pointed out for the first time a probable connection between his theory and the theory of electrons.

In the same year, 1904, Prof. J. J. Thomson proposed a hypothesis that atoms consist of electrons within a uniform sphere of positive electricity. He discussed the arrangement of the electrons on this supposition. A single electron would go to the centre of such a sphere. Two electrons, owing to their mutual repulsion, would be in equilibrium at a distance from each other equal to the radius of the sphere. Three electrons would form an equilateral triangle, four a tetrahedron, six an octahedron; but Professor Thomson says that he has been unable to solve the general problem for n electrons distributed in a sphere. He gives, however, a rather remarkable solution on the supposition that the electrons are situated in a plane. In that case they will arrange themselves in concentric rings, and for a given number of electrons there is only a single stable arrangement. Further than this, with a given number in the exterior ring, the number which can be placed within is limited by two extremes. The most suggestive case of this kind is that with 20 electrons in the outer ring. The total number of electrons with such an outer ring can never be less than 59 and cannot exceed 67. This might be supposed to correspond to a group of nine elements of the periodic system from helium to neon or from neon to argon. The arrangement with 59 electrons, if it lost one, would be compelled to rearrange to a form having only 19 electrons in the outer ring, but, owing to the positive charge acquired by the loss of the electron, it would immediately acquire another and go back to its original form. Such an element would have a valence of 0 for a positive charge, and Professor Thomson suggests that this would correspond to such an element as helium or neon.

This paper of Professor Thomson's is of special interest be-

cause it contains, for the first time, the suggestion that two atoms may be held together by the electrical forces resulting from the transfer of an electron from one atom to another. The hypothesis of an arrangement of electrons within a sphere of positive electricity has been almost entirely abandoned in favor of the belief that atoms contain a positive nucleus which is very small in comparison with what may be called the effective size of the atom, and that electrons rotate around this nucleus at a considerable distance. Rutherford has been one of the leading supporters of this idea, and he bases an argument for it especially on the fact that when positively charged helium atoms are shot through a thin metallic film many of them pass through without deflection, while a few are scattered through a wide angle.

FIG. 10.



The reason for the scattering will be understood from this figure (Fig. 10),[2] which represents an atom with a small positive nucleus around which two electrons are rotating. If a positive helium atom were shot through the orbit of the electrons at a high velocity it would not be deflected appreciably unless it were to pass very close to the central nucleus. In case it came near the nucleus, however, it would be repelled and thrown off at an angle.

Since Prof. J. J. Thomson first suggested that atoms may be held in chemical combination by the electrical forces resulting from the transfer of an electron from one atom to another a number of chemists have used the electron theory in discussing chemi-

[2] A similar figure has been used by Prof. W. D. Harkins in an address which he has given.

cal problems. Thus Hentschel pointed out that the three atoms of chlorine in nitrogen trichloride are equivalent to six atoms (three molecules) of free chlorine in oxidizing power. In terms of the electron theory this is easily explained by assuming that in nitrogen trichloride the nitrogen atom has gained three electrons, becoming negative, while each chlorine atom has lost an electron, becoming positive. In order to convert the chlorine of the trichloride to the form in ordinary chlorides each chlorine atom must gain *two* electrons. In free chlorine, on the other hand, one chlorine atom has lost an electron, while the other has gained one, hence the two atoms of free chlorine require only two electrons to convert both atoms to the negative form. Professor Stieglitz pointed out, several years before the electron theory was used in discussing chemical problems, that in reacting with water the negative atom of a molecule of free chlorine combines with the positive hydrogen of the water, while the positive chlorine atom combines with the negative hydroxyl of the water to form hypochlorous acid.

The ordinary valence theory, which takes no account of the electrical forces, gives no satisfactory reason why ammonium hydroxide ($H\text{-}O\text{-}NH_4$) should in ionization, give hydroxyl ions, while nitric acid ($H\text{-}O\text{-}NO_2$) gives hydrogen ions. When we write the formulas in the light of the electron theory, as shown in this diagram, we see that the negative oxygen of the

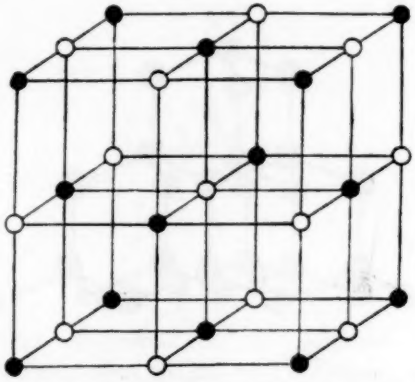
DIAGRAM 2.

hydroxyl may be held strongly by the positive nitrogen atom of the nitro group (NO_2), while it is not held so strongly by the nitrogen atom of the ammonium group (NH_4). The nitrogen atom of the latter group has lost four electrons and gained one, if we assume a localization of valence electrons within the atom.

I have referred to the X-rays which are generated when the stream of electrons in a Crookes tube impinges on the glass of the bulb. For a long time there were great differences of opinion among physicists as to the real nature of these rays. It is now pretty well established that the X-rays are of essentially the same nature as light-waves, but have an exceedingly short wave-length.

Most of you have learned of the so-called gratings produced by ruling ten thousand or more lines to the inch on a smooth surface. A spectrum is produced by the reflection of light from such a surface, and if the distance between the lines is known it is a simple matter to calculate the wave-length of a bright line of the spectrum found at a particular angle with the surface of the grating. Conversely, if we know the wave-length of the light of the bright line and the angle, it is possible to calculate the distance between the lines of the grating. Laue, the Braggs, Mosely, and others have applied a similar, though not quite identical, principle to the study of X-ray spectra. They have used as gratings the regular rows of molecules in crystals of salt, the diamond, and other substances.

FIG. 11.



Two results of extreme interest have already come from this study. It has been discovered that each chemical element has a characteristic two-line X-ray spectrum. From these spectra what are known as atomic numbers have been deduced, which fix the position of each element in the periodic system. It is well known that some elements, such as tellurium, have atomic weights which do not fit into the proper place in the periodic system. The atomic numbers of all of the elements so far studied are in the proper order, and we can now say that the atomic number of an element is even more characteristic than its atomic weight.

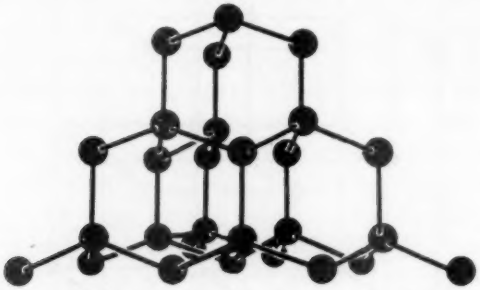
The X-ray spectra have also been used by the Braggs, especially, to decipher the structure of crystals. This slide (Fig. 11) shows the structure of a crystal of potassium chloride as demon-

strated from the results of these experiments, and the next (Fig. 12) gives the very different structure of a diamond.

I think almost nothing has given me such a feeling of the loss which is coming to the world from this dreadful war as the knowledge that Mosely, one of the most brilliant workers in this field, though a young man of only twenty-six, was killed at the Dardanelles.

There must surely be a very close relation between the structure of atoms and the motion of the electrons within them and the spectra of the elements. Some years ago an element called nebulium was discovered by its spectrum in the great nebula of Orion. The element has not been found in the earth. Nicholson, from a study of the spectrum of nebulium, came to the conclusion that the atom of the element contains four electrons rotating

FIG. 12.



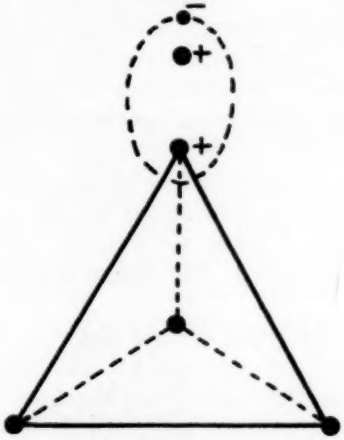
about a positive nucleus. At the same time he said that there were two of the spectrum lines of the nebula which he could not account for by this hypothesis. The same day that he presented his paper in England an astronomer, Wolff, gave a paper in Heidelberg in which he showed that the nebula consists of two parts, and the two lines which Nicholson could not explain came from a different part of the nebula from the rest. The two workers were entirely independent and were interested in different problems, so that the coincidence is remarkable, to say the least.

The work of physicists during recent years has led to the conclusion that the electrons within the atoms of the elements are in a very rapid rotation about positive nuclei. Chemists, on the other hand, have spoken of the transfer of valence electrons from one atom to another without any reference to the motion

of the electrons. It seems possible to unite the two points of view by the following hypothesis.[3]

Let us suppose that two atoms which have an affinity for each other are brought close together. A valence electron which is rotating around a positive nucleus in the first atom may find a positive nucleus in the second atom sufficiently close so that it will include the latter in its orbit, and it may then continue to describe an orbit about the positive nuclei of the two atoms. During that portion of its orbit within the second atom that atom would become, on the whole, negative, while the first atom would be positive. During the other part of its orbit each atom would be electrically neutral, and the atoms might fall apart. When

FIG. 13.



we remember, however, the tremendous velocity of the electrons and the relatively sluggish motions of the atoms, it seems evident that the motion of an electron in such an orbit might hold two atoms together. In ionization the electron would, of course, revolve about the nucleus of the negative atom, leaving the other atom positive. It seems impossible to explain ionization otherwise than on the supposition of the complete transfer of the electron. This complete transfer in ionization is one of the strongest arguments against the magneton theory as the only explanation of chemical combination.

[3] This has now been published in the *Proceedings of the National Academy of Sciences* and in the *Journal of the American Chemical Society*.

An interesting feature of the hypothesis proposed is that it may be used to account for that localization of affinities in particular parts of atoms which is indicated by many of the properties of organic compounds. Thus if we suppose that there are four (or eight) positive nuclei in a carbon atom, around which valence electrons may rotate, an atom of hydrogen may be held to the neighborhood of one of these nuclei as indicated in the figure (Fig. 13).

A few years ago we were accustomed to think of atoms as "manufactured articles," indivisible and unchangeable. The phenomena of radio-activity and the electron theory have demonstrated that atoms are extremely complex entities which may disintegrate into simpler parts. The conclusion is almost irresistible that they may also be formed from simpler parts. The atoms are also tremendous storehouses of energy for which we have not yet found the key. During the last sixty years chemists have deciphered the structure of thousands of compounds of carbon. A hundred years ago this knowledge would have seemed an impossible dream. To-day it is a practical reality, lying at the very foundation of our manufacture of dyes and explosives. Our knowledge of the structure of atoms is still a dream with very shadowy outlines, but I think we may be confident that a not very distant future will see this dream translated into definite details.

I think we may be quite certain that the electron theory is with us to stay, although the theory has found many changes and a very rapid development during its short life, and I cannot do better than to close with the words of Professor Thomson:

"The theory is not an ultimate one; its object is physical rather than metaphysical. From the point of view of the physicist, a theory of matter is a policy rather than a creed. Its object is to connect or coördinate apparently diverse phenomena, and, above all, to suggest, stimulate, and direct experiment. It ought to furnish a compass which, if followed, will lead the explorer further and further into unexplored regions. Whether these regions will be barren or fertile, experience alone will decide; but at any rate, one who is guided in this way will travel onward in a definite direction and will not wander aimlessly to and fro."

A NEW PRINCIPLE IN THE FLOW OF HEAT.*

BY

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Member of the Institute.

WHEN in the usual combustion process the high-temperature flame impinges on a surface which is maintained at a much lower temperature, as for instance in the boiling of water in steam boilers, in cooking utensils on gas stoves, etc., the sudden chilling of the hot gases causes a very thin film of extremely high thermal resistance to form over the flame side of this surface; all the heat which flows usefully from the flame to the water must pass through this very high resistance, which means that the rate of transference of this useful heat is greatly reduced thereby, and that the usual method of boiling water is therefore a very imperfect one.

The existence of this film is shown in the well-known experiment of boiling water in a cup of paper; also by the fact that a piece of ordinary paper, like a postage stamp, pasted on the fire side of a vessel in which water is boiled, will not be charred, though when several are thus pasted over each other the outer ones will become charred. The latter shows that the thickness of this film seems to be of the order of magnitude of about 0.005 inch, hence it is extremely thin. If the flame temperature is taken as about 1350° C., and that of the water is 100°, the drop of temperature through this film will be about 1250° C., showing an extremely high thermal resistivity.

Based on the heat flow through the bottom of an ordinary tin cup while water is boiling in it, the resistivity of this film figures out to be of the order of magnitude of about 79,000 in gramme-calorie-cm.-cube units, which means that a difference of temperature of about 79,000° C. would have to be maintained between the two opposite faces of a centimetre cube of such a film to cause one gramme-calorie of heat to flow through it per second. The resistivity of copper in terms of this same unit is only about 1.26, and that of felt is about 8400.

The resistivity of this film is so extremely high as compared with that of the best thermal insulators, that it is a question

* Communicated by the Author.

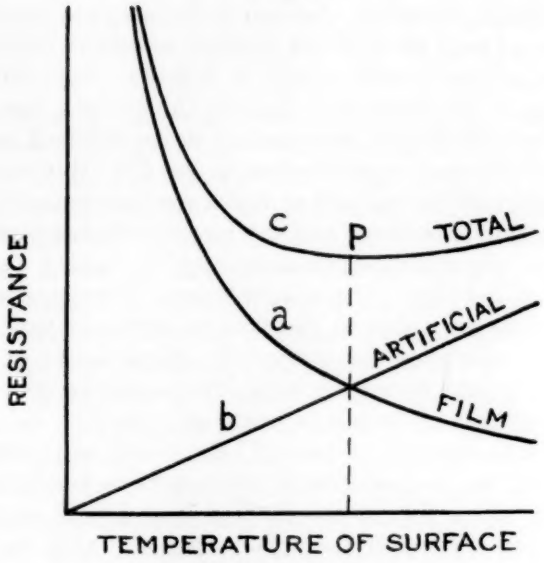
whether it is really a true resistance; possibly there exists what might be called a counter thermo-motive force analogous to a counter electro-motive force, which latter may sometimes for convenience be stated in terms of its equivalent in electrical resistance; or possibly the law of the transferrence of the momenta of moving masses may apply to the oscillations of the molecules which constitute thermal energy, in which transferrence it is the momenta and not the energies which are transferred equally; and the density of the cooler gases (the mass per cubic centimetre) is greater than that of the hotter ones; or a relatively very cold surface may have a tendency to reflect rather than transmit some of the heat waves. But, however the production or the physical nature of this film may be explained, the facts are that it exists and that it very greatly obstructs the flow of heat in steam boilers, water heaters, cooking utensils, etc. Until more is known about its physical nature it may in practice be treated as though it were a thermal resistance, as it acts like one.

A study of the properties of this film, by the writer, showed that its resistance diminishes greatly as the difference of temperature between its two faces is decreased. The temperature of the flame and of the water being fixed, the only way to accomplish this is to greatly increase the temperature of the fire side of the vessel. This can best be done in practice by inserting between the hot and the cold surfaces of the vessel an artificial thermal resistance of such magnitude that the current of heat flowing through it will maintain the hot side at a high temperature. As the difference of temperature between the two ends of a thermal resistance is a function of both the resistance and the flow of heat (like in the electrical analogy), and as the greatest possible flow of heat is what is desired, it follows that this artificial resistance should be made of the best possible heat conductor, so that its resistance may be made as low as possible; it should therefore be made of metal rather than of insulating materials.

The thermal relations are shown roughly in Fig. 1. The ordinates represent the thermal resistances in the path of the heat flow; the abscissæ the temperatures of the flame side of the vessel. The rapidly falling curve *a* then shows approximately how the resistance of this film (or its equivalent expressed in terms of thermal resistance) falls as the temperature of that surface

rises. The rising curve *b* shows approximately the thermal resistances which must be inserted to bring that heat-absorbing surface to those temperatures. And curve *c* is the total resistance —that is, the sum of the two others; it is this that governs the flow of heat from flame to water, and it will be seen to have a minimum point *P* beyond which it is no longer advantageous to increase the artificial resistance. Hence by increasing this resistance the flow of heat increases greatly up to a maximum point and then diminishes again. These curves are based on ex-

FIG 1



Approximate thermal relations.

perimental results and not on theoretical deductions, and they are only approximate, as many other factors enter also.

Curve *a* may be represented by

$$xy = k,$$

which is only crudely approximate; the data for it are not yet accurately known.

Curve *b* may be represented similarly by

$$y = nx,$$

which also is only crudely approximate, as it curves downward.

The value of x for the point of intersection, therefore, is

$$x = \sqrt{k/n}.$$

The equation of curve c, of which the ordinates are the sum of the other two, then will be

$$Y = k/X + nX,$$

Placing the first differential coefficient equal to zero, gives

$$X = \sqrt{k/n},$$

This is the same as the value of x for the point of intersection, which shows that a minimum point exists above the point of intersection, at which, therefore, the two resistances are equal.

The flow of heat through the artificial resistance and through the film being necessarily equal, it follows, from the above analysis, that in this method of heating the greatest heat flow is obtained when the drop of temperature in the artificial resistance is made approximately equal to that in the film; this means that the temperature of the surface at which the heat enters the walls of the vessel should be about midway between the temperatures of the flame and the water, hence about 725° C. (about 1365° F.), which is a dull red heat. The more this drop of temperature in the artificial resistance is due to the flow of heat and the less it is due to actual resistance, the better. As copper is one of the best heat conductors, the maximum in practice would be that obtained when the artificial resistance is made of copper.

The limit to the rate of flow of heat would be reached when it is so rapid that the spheroidal state starts to take place; that is, when the water side of the surface is no longer kept wetted by the water. Although the writer has been able to increase the heat flow about 27-fold by this method, there were no indications that the spheroidal state had been closely approached, hence there is no probability of reaching it, and if there is, it could be easily avoided by attaching lugs to the water side of the vessel.

Unlike in the analogous case of electrical energy, there is no loss of heat energy or efficiency in overcoming these two thermal resistances; all the calories of heat which enter the hot side issue again from the cold side (assuming perfect lateral heat insulation). The resistances therefore affect only the *rate* of transmission through a given cross-section. But indirectly the thermal

efficiency in this case increases with this rate; there are always some unavoidable losses of heat, and if a given quantity of water is evaporated by the same flame in, say, half the time, these losses will take place during only half the time, hence will be halved. A distinction must therefore be made between the rate and the efficiency; the writer has succeeded in increasing the rate about 27 times, but the thermal efficiency in ordinary steam boilers is from 25 to 75 per cent., possibly even a little higher in some very good boilers, and therefore it could not be increased 27-fold, though the losses might be reduced to one twenty-seventh of what they were, if the time of heating could be reduced that much.

In practice the most convenient way to make these artificial resistances is by attaching metallic lugs to the flame side of the vessel. These must be so proportioned in diameter and length that the heat flow through them will maintain their hot ends at a temperature about half way between that of the water and the flame, which is at about a dull red heat; unless so proportioned they will not act as described and would merely add a little to the heat-receiving surface. Such lugs, when properly proportioned, act as though they pierced thermal openings through that highly-resisting film through which the heat then rushes into the water very rapidly, as is shown by the water boiling with extreme rapidity directly over the tops of those lugs.

When these lugs are made shorter and thicker or longer and thinner than they should be, the flow of heat diminishes, as indicated by the curve *c*. As the same thermal resistance may be obtained with short, thin lugs or with long, thick ones, provided the ratio of the diameters and lengths are the same in both, there is a choice open. Practical considerations, such as the expense, weight, space, etc., will generally decide this. Theoretically their best lengths (when vertical) would be such that the above-described relations hold good also for the sides of the lugs over which the partially cooled gases rise; the temperatures of the rising gases and of the vertical lugs both diminish from the hot end up, hence if they both decrease in the same ratio, the water temperature being considered as zero, there will be the greatest possible absorption of heat by the lateral surfaces of the lugs. This means a certain freedom of flow of the hot gases, hence the spacing should not be too close.

The former theory concerning the use of lugs on the heated

surface has been that they increase the heat-absorbing surface. While it is undoubtedly true that by increasing the surface covered by this film its resistance as a whole is reduced somewhat, yet the writer's researches have shown conclusively that the increased flow is by no means a function of this surface, and that the older theory is therefore quite fallacious, which no doubt explains why this frequently proposed method of increasing the rate by increasing the surface has not come into general use; the principle was not the correct one. Increasing the surface without breaking down the film may give a small percentage increase, but by breaking down the film resistance as described an increase of several thousand per cent. was obtained.

Special attention was given to this theory of the surface in the writer's researches and many comparative tests were made; the results bore no relation whatsoever to the surface, but they were all in accord with the principle above described. In one case the surface was made four times as great as in another, yet the results were even worse. In another case the lengths and cross-sections were the same, but the surfaces were greatly different by making one set of lugs round and the other flat, yet the latter gave no better results.

The many-fold increase of flow obtained by properly proportioned lugs refers to the flow through the lugs as compared with the flow through the same area of the vessel as that of the cross-sections of the lugs, and therefore is of interest chiefly in showing the correctness of the principle. In practice this extreme result of 27-fold could not be reached, and probably could not even be very closely approached. The lugs in this case were rather far apart; when closer together the flow in each lug becomes less, but the area covered by them then becomes so much greater that the flow per square inch of total surface of the vessel is greater.

With ordinary tin cups over a quiet Bunsen flame of about the same diameter as the bottoms of the cups, and shielding the sides of the cups from the flame, the same amount of water was evaporated in nearly one-quarter of the time with nearly one-quarter of the amount of gas. With the ordinary gas stove, in which it is not possible to get the best relations between flame and lugs, the evaporation was about twice as fast with half the gas. Further refinements in the best application of this principle will probably lead to still better results, especially when the flame

also can be made the most appropriate for this purpose. If in steam boiler practice the rate could thereby be merely doubled, it would be of great importance, as it would diminish the size of the boilers by about a half.

The flow through the cup without lugs was about 1.25 gramme-calories per second per square centimetre. Through the lugs themselves as much as 34 gramme-calories were obtained, which is about 27 times as fast. Through the whole bottom, including the space covered by the lugs and that between them, the rate was about 4.35, which is nearly four times that in the cup without lugs, and the best conditions had no doubt not yet been reached. The ordinary boiler practice, three pounds of water evaporated per hour per square foot at and to 212° F., is equivalent to 0.218 gramme-calorie per second per square centimetre; in such boilers the flames and the heating surfaces cannot be as well adapted to each other as in direct heating by gas flames, which explains why this is only about a sixth of the rate obtainable in boiling over gas stoves.

A Lamp Filament for Motion-picture Machines. ANON. (*Electrical World*, vol. 70, No. 13, p. 620, September 29, 1917.)—Because in any faint source of light the rays entering the condensing lenses necessarily form a conical beam, Albert S. Moffat, of Belmont, Mass., proposes, in patent No. 1,222,119, to dispose an incandescent-lamp filament in a hollow pyramidal form, the base of which is similar in contour to the picture space to be illuminated, and to have the filament composed of a long helix wound in a spiral about such a pyramid.

To this end the filament will not only intensify the light emitted therefrom, but will concentrate it upon the rectangular space occupied by a motion-picture section. In the usual form of light the rays issue in the shape of a cone whose base is circular and consequently must lap over the rectangular picture space to an extent fully equal in area to that of the space utilized. By having the filament in a helix a maximum of light-rays is obtained in the minimum of space. By having the helix wound as a hollow pyramid the emitted rays are concentrated upon a smaller space than would be the case were the helix coiled in a single plane parallel with the plane of the picture. This is because the rays from the inner turns can pass the outer turns only by issuing in a straight line within the outer turns, and so on to the film, conforming in contour to the rectangular shape of the picture.

Historical Note on the High-tension Magneto. A. P. YOUNG. (*Aerial Age Weekly*, vol. 6, No. 2, p. 64, September 24, 1917.)—The degree of success achieved in the evolution of the combustion motor has at all stages been primarily dependent upon the efficiency of the ignition system used, and it is no exaggeration to say that the rapid strides which have been made during recent years in the construction of the petrol motor have mainly resulted from the very satisfactory high-tension ignition system that has been available. All electrical systems of ignition are direct descendants of Faraday's great discovery of electro-magnetic induction, made during the autumn of 1831, when for the first time in the world's history he succeeded in producing a spark by magnetic means.

The first system of electric ignition ever used was devised by Lenoir in 1860. He utilized the high-tension spark of a Ruhmkorff coil for ignition purposes, employing a high-tension distributer for connecting the secondary winding first to one plug, then to the other. It is worth noting that the modern battery system of ignition now used most extensively in the United States is strikingly similar to the old Lenoir system, even to the detail of introducing an extremely small air-gap between the rotating metal brush and the distributer segment, a method of distribution that is now being followed on magnetos. Lenoir was also the inventor of the spark plug, and the type of plug which he designed for use in conjunction with his ignition scheme of 1860 had all the features of the modern spark plug.

Marcus appears to have been the first man to construct a magneto for ignition purposes. His was a low-tension machine having the new familiar form of H-armature, the current induced in the winding being broken at predetermined times in the cylinder by cams and levers. In 1898 Simms and Bosch developed a low-tension magneto, using a fixed H-armature and rotating segments for producing the necessary flux changes in the armature core. This is of special interest because subsequently, by the addition of a secondary winding on the same armature core, a high-tension magneto was evolved.

The Bosch Company of Stuttgart, Germany, must receive the credit for having thoroughly established the fact that a high-tension magneto can be manufactured on a commercial basis to give reliable and efficient ignition in practice. Although this important industry was developed in Germany, the modern high-tension magneto was first conceived in France by M. Boudeville, who unfortunately omitted to include a condenser in his scheme for eliminating sparking at the contact points. A condenser is a vital part of every magneto; without it the machine would be quite impracticable. It is surprising that Boudeville should have overlooked this feature, because here again the idea of using a condenser for such a purpose is of French origin, Fizeau, in 1853, being the first to suggest connecting a condenser in parallel with the contacts on a Ruhmkorff coil to prevent excessive sparking.

PHYSICS OF THE AIR.*

BY

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CHAPTER X.

ATMOSPHERIC CIRCULATION (*continued*).

Winds Due to Widespread Heating and Cooling (continued).

EXTRA-TROPICAL CYCLONES.

General Remarks.—The strong winds and heavy precipitations of middle latitudes are associated with the occurrence of low barometric pressure, while gentle winds and clear skies as commonly are associated with the occurrence of high barometric pressure. Hence the cyclone, or that system of winds that accompanies and surrounds any considerable region of minimum pressure, and the anticyclone, or that system of winds that belongs to and encircles a region of maximum pressure, deserve and have received a vast amount of observation and study. Nevertheless, in many respects—in their origin, in their temperature distributions, and in the laws of their movements—cyclones and anticyclones still remain in great measure the meteorological mysteries they have always been.

Although the cyclones and anticyclones of extra-tropical regions are as closely associated and as fully the complements of each other as are hills and hollows, it nevertheless will be convenient to consider them independently. It will also be convenient first to summarize the facts of observations, and then to string these facts together on the thread of a provisional theory.

Size.—The area covered by an extra-tropical cyclone, the largest of all distinctive storms, nearly always amounts to millions of square kilometres. In North America the average diameter of these storms is estimated to be, roughly, 2500 kilometres (1553 miles), which probably is not greatly different from their average diameter on other continents. Over the North Atlantic their diameters are still larger, while the greatest of all in size is the semipermanent or winter Aleutian "low," which appears usually

* Continued from page 836, vol. 184, December, 1917.

to be much larger than the travelling cyclones of the Atlantic or even the great semipermanent Icelandic "low."

Direction of Movement of the Cyclonic Centre.—The direction the centre of a cyclone travels, wherever it may be located, is substantially the same as that of the higher clouds or of the atmosphere at 6 to 10 kilometres above sea level. In general, therefore, the cyclones of middle latitudes travel from west to east, with (in the northern hemisphere) a southerly dip over continents and a northerly deflection over oceans. Cyclones, for instance, that develop between latitudes 30° and 45°, in the western United States, usually turn northeast before reaching the Mississippi River. Farther west they may move east, or even somewhat southeast.

Locus of Maximum Cyclonic Frequency, or Chief Paths of Cyclonic Storms.—Probably no part of the earth's surface more than 3 or 4 degrees from the equator is wholly free from cyclonic storms, but the frequency of their occurrence varies greatly with respect to both time and place. Beginning with the West Pacific: During summer and fall many cyclonic storms come from the general region of the Philippines and move northeast across or on either side of Japan. Winter and spring cyclones enter on this same general course at latitudes 30 degrees to 40 degrees; some, presumably, being of oceanic origin, while others obviously either develop within or cross over China. In any case, the general track of these storms is along the Japanese and Kurile Islands, and thence east over the Bering Sea. The main path is then southeast across the Gulf of Alaska, with the storms, including off-shoots from the Aleutian "low," crossing onto the continent anywhere between latitudes 40 degrees and 60 degrees, but apparently most frequently in the general neighborhood of Vancouver Island. These Pacific storms usually cross the continent nearly from west to east, dipping slightly south over the Great Lakes, and finally leave it by way of Newfoundland. A smaller number of storms from the North Pacific dip far south, somewhat like the Mediterranean branch mentioned below, to about latitudes 35 degrees to 40 degrees, but usually recurve west of the Mississippi and join the main course as they reach the Atlantic. Those that originate in or cross over the central and southern portions of the United States, as also those that come from the Gulf of Mexico, move northeast and gradually merge

their paths with that of the Pacific storms anywhere from the Great Lakes to the Newfoundland Banks. Other cyclones coming up from the Florida and West Indies regions follow the coast, not far off shore, and also merge their paths with that of the others in the neighborhood of Newfoundland. Half-way or more across the Atlantic the path of maximum storm frequently breaks up into at least three distinct routes. The main route turns far north, usually by way of the Norwegian Sea, then southeast, entering Russia in the neighborhood of the White Sea, and passing on toward Central Asia. A second route turns southeast and crosses Europe generally along the northern side of the Mediterranean, and then turns north either across Austria toward northwest Russia or by way of the Black Sea toward Central Asia. A third and least frequented route, commonly running just south of Ireland, appears to cross both the North and the Baltic Sea, and then, like the others, to move on toward Siberia and central Asia. The cyclonic storms of central and northern Asia do not appear to be very numerous. Nevertheless, their track of maximum frequency seems to turn south, as does the similar track over North America, as far as Lake Baikal, thence probably to the Sea of Okhotsk and across or to the south of Kamchatka to the main storm path north of the Aleutians, as already explained.

In the southern hemisphere the path of maximum storm frequency appears closely to follow the 60-degree parallel of latitude. Presumably it dips poleward at both the Ross and the Weddell Sea, as each of these is a region of semipermanent low pressure.

It must be remembered, in this connection, however, that in both the southern hemisphere and the northern cyclonic storms occur almost everywhere, and therefore that the routes above described are only paths of maximum cyclonic frequency and not of exclusive travel.

Velocity of Travel.—The velocity with which the centre of a cyclonic storm moves along its path varies greatly. It depends upon the season, being fastest in winter and slowest in summer; upon location, being faster in America than in Europe, for instance; and, finally, upon the individual storm.

The following table gives average velocities for different parts of the northern hemisphere. Those pertaining to the United States were computed from a table of average 24-hour move-

ments as determined by Bowie and Weightman [48] from 16,239 observations, covering the years 1892–1912, inclusive. The others are from Hann's "Lehrbuch der Meteorologie," 3d edition, p. 518.

Average Velocity of Cyclones in Metres per Second.

(For the United States the velocity is also given in miles per hour.)

	United States	Japan	Russia	North Atlantic	West Europe	Bering Sea.
Winter.....	(29.9) 13.4	12.4	10.8	8.2	8.0	8.5
Spring.....	(23.7) 10.6	11.1	9.2	8.3	7.2	8.5
Summer.....	(20.7) 9.3	7.8	8.0	7.4	6.6	10.3
Fall.....	(24.5) 11.0	10.6	9.6	8.3	8.2	9.3
Year.....	(24.7) 11.1	10.5	9.4	8.05	7.5	9.1

Frequency.—The frequency of the occurrence of cyclonic storms varies not only from place to place, as already explained, but also at any given place, or even over an extensive area—probably an entire hemisphere—according to season. Tropical cyclones, it will be recalled, are far more frequent during summer and early fall than during winter. Mid-latitude cyclones, on the other hand, have exactly the opposite relation of frequency to season, being, in general, most numerous in winter and least numerous in summer. Exceptions to this rule apply to the paths of tropical cyclones next after the recurvature, provided we regard such storms as having them become extra-tropical. Perhaps exceptions also apply to certain regions on the poleward sides of the main cyclonic routes, since these are farthest north in summer and farthest south in winter. This, however, is not certain. A statistical investigation might show that even the greatest increase due to latitude shift is more than compensated by the general seasonal decrease in frequency.

When all storms are counted that appear in the United States or Southern Canada, whether short or long lived, weak or intense, in appears [49] that the frequency of summer (June, July, and August) "lows" is to that of winter (December, January, and February) "lows" approximately as 5 to 8. On the other hand, if only long-lived cyclones are considered, it appears [50] that in the

[48] *Monthly Weather Review*, Supplement No. 1, p. 8, 1914.

[49] Bowie and Weightman, *Monthly Weather Review*, Supplement No. 1, p. 7, 1914.

[50] U. S. Weather Bureau Bulletin A, p. 6, 1893.

United States the frequencies of summer to winter storms are about as only 2 to 9, and those of Europe as 3 to 10.

In either case, then—that is, whether only the longer lived and more intense "lows" are counted, or whether all, of whatever magnitude and duration, are included—it seems that cyclonic storms are most frequent during winter and least frequent during summer. Further, the extra-tropical storms of winter are not only more numerous than those of summer, but also, in general, longer lived, more intense, and faster moving.

Direction of Winds.—From the directions of winds in and about a region of low barometric pressure, as given on synoptic charts, it is often, perhaps usually, inferred that cyclonic winds circulate spirally inward and upward and then outward and upward, counter-clockwise in the northern hemisphere, clockwise in the southern, around a storm axis. This indeed is, in general, the course of the winds in tropical cyclones, especially in those that are violent and of small diameter, as the eye of the storm and directions of cloud movements clearly indicate, but it does not apply to extra-tropical cyclones, except, perhaps, to the occasional ones of great violence and small diameter. Extra-tropical cyclones rarely have clear centres, as they would if the circulation about them was closed or along spiral paths of repeated turns. Neither, in general, is a closed circulation indicated by the movements of the clouds. Again, it often happens that the velocity of the forward moving wind of a cyclone is less than that of the storm itself, so that instead of flowing around the storm centre it necessarily is left behind.

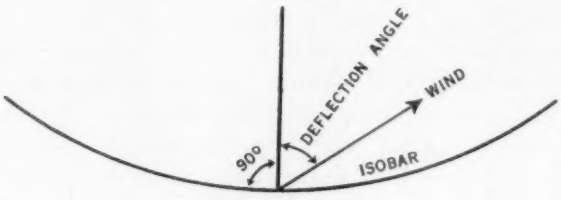
Synoptic weather charts, therefore, show instantaneous wind directions, but not wind-paths. This is because the storm condition itself is moving forward—moving, indeed, with a velocity nearly always comparable to, and at times even faster than, that of the lower winds themselves.

The main body of the storm winds, those below an elevation of 5 or 6 kilometres, except everywhere near the surface, and also generally about the poleward side above 2 to 3 kilometres elevation, blow, in the cyclonic sense, roughly parallel to the surface isobars. This does not mean that the path of any given particle of air is around and around the centre of low pressure, because, as above explained, this centre itself and its system of isobars are both in rapid transit. Near the surface the velocity is so slowed

down that the deflection forces no longer balance the horizontal pressure, and therefore the winds of this level are directed inward at a considerable angle across the isobars. Through the poleward half of the storm area the horizontal temperature gradient is nearly always opposite in general direction to the horizontal pressure gradient at the surface. Therefore, with increase of elevation in this section the pressure gradient usually weakens from the start and later reverses at the height of only a few kilometres; while the winds first increase (where the surface drag rapidly decreases) to a maximum, then decrease, and later more or less reverse in direction.

Deflection Angle.—The angle between the surface wind direction at any place within a cyclonic storm and the normal to the corresponding isobar, the "deflection" angle (Fig. 47), is great-

FIG. 47.



Deflection angle.

est, or the surface winds most nearly parallel to the isobars, *a*, when the winds are swiftest and thus develop the strongest deflective forces—therefore greatest to the south and east of the storm centre and least to the north and west, *b* when the velocity of the storm as a whole is least, *c*, in the summer time, because during this season the storm movement is less than during other seasons, *d*, over water where it is roughly 80 degrees, because the surface drag is less here than over land where the "deflection" angle averages only 40 degrees to 50 degrees.

It is important to note also that usually the deflection angle does not greatly change with distance from the centre. This follows from the fact that the horizontal pressure, the wind velocity, and the consequent surface friction and percentage loss of gradient velocity all are roughly constant in any given direction from the centre, so long as only points distinctly within the storm area are considered.

With increase of elevation and consequent decrease of surface drag the deflection angle over land gets larger by 25 or 30 degrees in the first kilometre. Beyond this elevation it still gains, but relatively very slowly. At an elevation of several kilometres the velocity of the air is decidedly greater than that of the storm, and therefore air that may have risen to this level is carried forward. Hence the main outflow of the extra-tropical cyclone is toward the east.

Wind Velocity.—As just stated, the pressure gradient and wind velocity are roughly constant along any given radius from the storm centre. This is because at middle and higher latitudes

Cyclonic Wind Velocity in Metres per Second and (Miles per Hour).

	Altitude	Surface 122 m.	500 m.	1000 m.	1500 m.	2000 m.	2500 m.	3000 m.	3500 m.	4000 m.
South quadrant	Winter	6.16 (13.8)	14.75 (33.0)	15.09 (33.8)	15.32 (34.2)	15.79 (35.3)	16.85 (37.7)	18.28 (40.9)	19.25 (43.1)	20.30 (45.4)
	Summer	5.42 (12.1)	9.64 (21.6)	10.69 (23.9)	11.31 (25.3)	12.22 (27.3)	12.91 (28.9)	14.08 (31.5)	15.69 (35.1)	17.21 (38.5)
	Year	5.84 (13.1)	12.24 (27.4)	12.93 (29.0)	13.38 (30.0)	14.07 (31.4)	14.94 (33.4)	16.24 (36.3)	17.53 (39.2)	18.81 (42.1)
West quadrant	Winter	6.70 (15.0)	13.47 (30.1)	13.39 (30.0)	13.93 (31.2)	14.75 (33.0)	16.18 (36.2)	17.31 (38.7)	17.31 (38.7)	....
	Summer	5.66 (12.7)	9.45 (21.2)	9.89 (22.1)	9.91 (22.1)	10.17 (22.7)	10.65 (23.8)	11.40 (25.5)	12.07 (27.0)	12.62 (28.2)
	Year	6.06 (13.5)	11.34 (25.4)	11.52 (25.7)	11.80 (26.4)	12.34 (27.6)	13.29 (29.8)	14.23 (31.9)	14.56 (32.6)	....
North quadrant	Winter	4.72 (10.5)	8.85 (19.8)	8.95 (20.0)	9.00 (20.1)	9.09 (20.4)	9.07 (20.3)	9.32 (20.8)	8.52 (19.0)	8.02 (17.9)
	Summer	4.84 (10.8)	7.85 (17.6)	8.37 (18.7)	8.45 (18.9)	8.81 (19.7)	9.11 (20.4)	10.26 (22.9)	10.63 (23.8)	10.63 (23.8)
	Year	4.79 (10.7)	8.36 (18.7)	8.66 (19.4)	8.72 (19.5)	8.94 (20.0)	9.08 (20.3)	9.78 (21.9)	9.57 (21.4)	9.32 (20.8)
East quadrant	Winter	4.50 (10.1)	10.45 (23.4)	10.02 (22.4)	10.43 (23.4)	10.58 (23.7)	11.64 (26.0)	12.11 (27.1)	13.37 (29.9)	14.59 (32.7)
	Summer	4.11 (9.2)	8.22 (18.4)	8.64 (19.4)	8.77 (19.6)	8.98 (20.1)	9.50 (21.3)	9.50 (21.3)	9.81 (21.9)	11.86 (26.5)
	Year	4.34 (9.7)	9.37 (20.9)	9.37 (20.9)	9.64 (21.6)	9.82 (21.9)	10.61 (23.7)	10.84 (24.3)	11.62 (26.0)	13.25 (29.7)

the deflective force is essentially geostrophic (due to the rotation of the earth) and to only a small extent cyclostrophic (due to circular motion). The winds, however, often are different in different portions of the storm area, and commonly strongest in its southern and eastern quadrants, where the isobars are most

crowded and the direction of the winds roughly that of the storm movement.

The actual average velocity of the wind in the different quadrants of a cyclone and at different elevations is given in the preceding table by Peppler,[51] based on a large number of measurements made during 1903–1908, at Lindenburg; latitude 52° 10′ N.; longitude, 14° 15′ E. Probably other mid-latitude regions have approximately the same average cyclonic wind velocities. This, however, is not certain, nor are there available sufficient data for determining the question.

Convection.—The vertical movements of the air, whether up or down, in an extra-tropical cyclone, or between such a cyclone and a neighboring anticyclone, are not known with much detail and accuracy. However, since the cyclone moves eastward with the air currents directed inward across the isobars, it is obvious that ordinarily the chief air convergence, due in part to increase of latitude, and hence the principal vertical convection, must be on the front or east side. Temperature also usually helps to locate the chief upflow in this quadrant, since its winds necessarily are from lower latitudes, and, therefore, relatively warm.

This localization of the uprising air explains why, other things being equal, most of the precipitation due to cyclonic storms occurs to the east and southeast (northeast in the southern hemisphere) of their centres.

Other things, however, are not always equal. Thus an extensive plain rising gradually to great elevations may slope in such direction that the mechanical or forced convection over it on any side of a cyclonic centre may approach, or even exceed, the thermal convection to the east. The Great Plains east of the Rocky Mountains illustrate this point. Here precipitation in the case of "stagnant" or slow-moving lows usually is most pronounced to the north of the centre where the winds are persistently up the slope. This is an extreme case, but it suffices to show that a rule relating to shifting winds and clear or foul weather that applies well in one place may not apply at all in another. Similarly, on the Pacific coast of North America, for instance, where the ocean is to the immediate west, the heaviest rains are to the south and west of the cyclonic centre.

[51] *Beiträge zur Physik der freien Atmosphäre*, 4, p. 95, 1911.

Classification.—Cyclones occur in extra-tropical regions with such great frequency that several such storms are nearly always present in each hemisphere. Naturally they have been much studied and therefore variously classified, especially according: to duration, as semipermanent and migratory; to season of occurrence, as summer and winter; to zone of origin, as tropical and extra-tropical; and to the place from which first reported as, for instance (referring to only those within or near the United States), Alberta, North Pacific, South Pacific, Northern Rocky Mountain, Colorado, Texas, East Gulf, South Atlantic, and Central.

All these classifications are useful, but not adapted to the present purpose, which is to group the cyclones, as far as practicable, according to their more important causes. Perhaps this end will be fairly well served by dividing them into *thermal* (identical with semipermanent), *insolational,* and *mechanical.*

Thermal (Identical with Semipermanent).—The name semipermanent cyclone—for which the alternate name, thermal cyclone, is here proposed for reasons that will appear below—or semipermanent "low," has been given to that system of winds of any region over which the barometric pressure habitually or seasonally averages lower than for the surrounding regions. The term generally is used as though it applied to but one and the same cyclone, however it might wander or even for a time wholly disappear. Thus, one always says *the* Icelandic "low," not *an* Icelandic "low." Similarly, *the* Aleutian "low," not *an* Aleutian "low." But, as stated, this applies only to average conditions. In reality there is no one permanent Icelandic "low," for instance, that retains its identity wherever it may be, but only a series of sluggish or temporarily fixed lows, all of which originate over, or, on invading, become intensified over, practically the same restricted region.

There are several semipermanent cyclones in various parts of the world. The nearest to continuously active of these, at least in the northern hemisphere, and at all times apparently one of the most productive of migrating cyclones, lies southeast of Greenland and southwest of Iceland. Another such region, active during winters only and known as the Aleutian "low," lies along and to the south and southeast of the Aleutians, extending into and including the Gulf of Alaska. The Norwegian Sea and, possibly,

the Sea of Okhotsk are other such high-latitude regions. The Gulf of Lyon is a low-pressure haunt during winter, as is also the Black Sea, and the Caspian Sea, as its monsoon winds definitely show. The Gulf of Mexico, over which occasional winter cyclones appear to generate, may likewise be added to the above list.

In the southern hemisphere the regions of most persistent lows are the Ross Sea and its counterpart, the Weddell Sea, on the other side of the continent.

All the above regions have surfaces warmer than those that at least partially surround them. The circulation induced by such temperature distribution is converted into a system of cyclonic winds by the deflective force due to the earth's rotation. The warm waters off the coast of Greenland and Iceland, for instance, necessarily maintain the atmosphere above at higher temperatures, level for level, than that of the neighboring ice-caps. Hence a practically continuous overflow of air from the one place, with compensating drainage and inflow from the other, is enforced by the existing and perpetually maintained distribution of unequal surface temperatures. These temperature contrasts are most pronounced, and the resulting Icelandic " low " most intense, during winter; but it prevails through summer also, for the simple reason that the necessary temperature gradients, though weakened during this season, are neither obliterated nor reversed—the water remains always warm in comparison with the ice-caps of both Greenland and Iceland, which persist from season to season and from year to year.

The Aleutian " low," on the other hand, is merely seasonal: it prevails only while the adjacent Alaskan and Siberian regions are snow-covered and relatively cold. When this snow is gone the temperature gradients are even reversed, and the off-shore drainage of winter is replaced by the on-shore winds of summer. Similar considerations and explanations obviously apply to all the other regions frequented by semipermanent cyclones.

Insolational.—Since warm gulfs and seas flanked by relatively cold land areas induce, as explained above, more or less permanent cyclones, it follows that warm peninsulas flanked by relatively cold water should also be generators of cyclonic wind systems. Similarly, any area of sufficient size that becomes heated through insolation to temperatures above those of the

adjacent regions should likewise induce or tend to induce a circulation of the cyclonic type. The Spanish peninsula shows, during summer, the phenomenon in question. It also occurs over the Alaskan peninsula onto which summer winds blow from the Gulf of Alaska, from Bering Sea and from the Arctic Ocean, obviously producing, through rotational deflection, a distinct cyclonic circulation. Similarly, the Great Plains often show daylight or insolational lows from which occasional cyclonic storms appear to originate.

Of course, entire continents show low average pressure during summer and high during winter, while in each case the opposite condition applies to the oceans. Such conditions, however, are not especially productive of storms, because the areas involved are hyper-cyclonic in size—so large, in fact, that they only modify the general or planetary circulation without producing local disturbances within it. Neither do temperature contrasts between areas that are very small in comparison with that of the average cyclone produce extensive precipitation, but mere local disturbances quickly smoothed out by the general circulation, or, at most, only thunder showers. In short, for the development of cyclones by temperature contrasts the warm area must be neither too large nor too small, neither continental in extent nor in size a mere island or bay.

Mechanical.—The mechanical "low" is divisible into two classes: (1) Permanent—in reality not a cyclone at all in the ordinary sense of a low centre with encircling isobars—and (2) migratory—the characteristic cyclone of middle latitudes. In the first class, certainly, and presumably in the second also, the low pressure is rather the *result* than the *cause* of the associated winds. Indeed, in the case of any steady wind, except those near the surface or close to the equator, its sustaining force (force in its direction) is small in comparison with the deflective force at right angles to its path due to the rotation of the earth.

Mechanical (Permanent).—There are two well-developed, permanent lows of this type (mechanical) and also an imperfectly developed third. These are (*a*) The equatorial low, which roughly follows the equator through its entire course, due partly to the relatively high temperature of this belt (to that extent an insolational "low") and partly to the right and left deflective forces of the westward winds of the northern and southern

hemispheres, respectively. (*b*) The Antarctic trough, encircling Antarctica generally between 60 degrees and 70 degrees S. and having an annual average pressure of about 740 mm., mechanically sustained jointly by the northward pressure of the swift west winds over the oceans and the southward pressure of the east to west component of the vigorous southeast air drainage or fallwinds of Antarctica. (*c*) The Arctic trough, irregular in outline and intensity and apparently only fragmentary.

Mechanical (*Migratory*).—The great majority of extratropical cyclonic storms are migratory, and apparently originate either by breaking off from or in some manner being induced by the semipermanent and insolation lows, or, occasionally, by somehow forming at almost any other place, especially along the more frequented storm paths. The genesis, development, and detailed structure of these storms are by no means well understood, and therefore the following tentative hypothesis in respect to their origin and maintenance is offered chiefly as a convenient mnemonic by which the principal known facts concerning them may be remembered.

Tentative Hypothesis of the Origin and Maintenance of Migratory Cyclones.—It will be recalled that the prevailing wind movement of middle latitudes is from west to east, and that to a first crude approximation (more nearly attained in the southern hemisphere than in the northern) parallels of latitude are followed with such velocity that the poleward pressure gradient is just balanced by the rotational deflection. Obviously, however, numerous surface inequalities, irregularities of temperature distribution, cloudiness, precipitation, and the like, prevent this gradient from being constant along any parallel of latitude or even remaining constant at any given place. Hence the prevailing winds themselves, being primarily under the control of this gradient, correspondingly vary in direction and velocity. Also, because of surface friction, there is much air leakage across the dynamical partition of swiftest winds (usually along parallels of 40 to 60 degrees) to higher latitudes, and, of course, an equivalent return flow.

Now let a disturbance, due to whatever cause, deflect a considerable and rather deep section of the eastward flowing air toward the adjacent pole. Immediately it flows eastward faster than before, in accordance with the law of the conservation of

areas, and thus crowds upon the air in front, unless it in turn has sufficient velocity to keep out of the way, a condition that probably does not usually obtain. Because this air comes from lower latitudes and therefore commonly is relatively warm and its absolute humidity often great, and also because it is flowing to regions where the meridians are crowded closer together, it necessarily rises, and in so doing usually yields abundant precipitation, whose latent heat materially aids to perpetuate the storm—continuously to develop a " low " in the forward quadrant.

Simultaneously as this broad body of air sweeps to higher latitudes an equivalent amount, necessarily to the westward, moves in the opposite direction. Indeed, this return branch may have contained the initial impulse; the results would be the same. Here, also, the law of the conservation of areas applies. The return current necessarily lags and in some measure checks the eastward flow of the air to the rear. In this manner the atmosphere between the two components of the horizontal circulation, the forward speeding up, the rearward lagging, is mechanically more or less expanded (stretched), while that on both sides is compressed. The lower air, especially in front of the storm centre, being retarded by friction and turbulence, flows spirally inward, then upward and out. The " low " thus, or however, formed, constitutes a travelling break in the partition between the mid-latitude and high-latitude circulations. In front of the " low " the primary circulation finds its way to colder regions, while to its rear return currents simultaneously bring equivalent amounts of other air to warmer sections. At any rate, whatever the region of extratropical cyclones, it is obvious that much of the interzonal circulation between middle and high latitudes, perhaps by far the greater part of it, occurs simultaneously on their opposite sides. Between the tropical and extra-tropical regions the chief intercirculation is through the trades and counter-trades—to lower latitudes by the former, mainly, and to higher chiefly by the latter.

Since the area covered by a cyclone or anticyclone is very great, averaging, roughly 2×10^7 square kilometres, it would seem, as abundantly supported by cloud movements, that each must directly involve at least the whole depth of the troposphere. On the other hand, the stratosphere, from its different temperature, humidity, and wind velocity, appears to be relatively passive, suffering rather than causing either cyclonic or anticyclonic effects.

According to this conception, the troposphere within a cyclonic area is mechanically expanded and, besides, has a marked upward component. It therefore must be cooled, though in the east quadrant, where the wind is from lower latitudes, the warming on that account may equal or even exceed the expansional cooling. Similarly, in an anticyclone the troposphere is mechanically compressed and also has a downward component, thus producing a temperature increase, except, possibly, on the east or forward side, where this effect may be equalled or exceeded by the transfer of colder air from higher latitudes. Hence, because of opposite directions of convection, upward (cooling) in the cyclone, downward (heating) in the anticyclone; contrary changes in pressure, decrease (cooling) in the cyclonic area, increase (heating) in the anticyclonic; and, presumably, inequality of radiating power due to differences of moisture content—the descending (warming) air of the anticyclone being relatively dry and thus heat preserving—one might expect to find, as observations (referred to later) show, that the troposphere is comparatively cold in cyclones and warm in anticyclones, except, perhaps, near the surface, where convection is less operative.

If, as seems likely, cyclonic and anticyclonic winds involve the troposphere through its whole depth, it follows from Egnell's law, $\rho v = a$ constant, with change of elevation, that the pressure gradient is also a constant, and, finally, that the pressure difference between a high and its neighboring low may be of the same order of magnitude at all levels up to the top of the troposphere.

Further, if the stratosphere is essentially inert in respect to the genesis and progress of surface storms, it clearly must sink to lower levels over cyclonic areas and be raised to higher over anticyclonic, and thereby itself undergo pressure and temperature changes,[52] and also briefly (during the formative stage) manifest cyclonic and anticyclonic wind systems.

Let a stratospheric column be dropped bodily a distance dh, and let the surrounding air come in until equilibrium is again established. At each level there obviously will result a change in pressure directly proportional to the pressure at that level. That is, throughout the column

$$\frac{dp}{p} = K, \text{ a constant.}$$

[52] Shaw, "Perturbations of the Stratosphere," M. O. 202, p. 47, 1909.

But, as is well known,

$$\frac{dT}{T} = C\frac{dp}{p},$$

in which T is the absolute temperature, and C a constant, 0.2843 for dry air. Hence, since T is constant, roughly, in the stratosphere, dT is also constant, and the upper air remains vertically isothermal, whatever the pressure increase or decrease. An increase of pressure in the stratosphere, such as presumably takes place over cyclones, *increases* its temperature, while a decrease of pressure, such as probably occurs over anticyclones, correspondingly *decreases* its temperature. In each case the pressure effect presumably is slightly enhanced by the coincident change in the intensity of radiation from below.

Suppose the temperature of the stratosphere over a cyclone should differ from that at the same place over the following anticyclone by 10° C., what, according to the above conception, will be the approximate change of boundary level? Let h be this change, and let the temperature of the stratosphere be 220°, absolute: Then since

$$\frac{dp}{p} = \frac{dh}{H},$$

in which H is the height of the homogeneous atmosphere, about 6450 metres at the assumed temperature, it follows that

$$\frac{10}{220} = 0.2843\,\frac{h}{H}, \text{ roughly,}$$

and

$$h = 1 \text{ kilometre, approximately.}$$

That is, the temperature of the stratosphere will increase or decrease at the rate of approximately 10° C. per kilometre enforced fall or rise, respectively, under the influence of cyclonic and anticyclonic disturbances.

While migratory cyclones of this nature, mechanical or counter-current, may originate almost anywhere outside the tropics, it is evident that some places are far more favorable to their genesis than others. Among such favorable places it is probable that the Gulf of Alaska is one of the most pronounced, at least during winter, since here the relatively warm water gradually creates a "low" that deflects in a northerly direction the air currents to the south and southeast, and to a southerly direction the air currents to the north and northwest. Hence a low formed over this gulf, or farther west along the Aleutian Islands, is likely to become accentuated on its eastern side through the advent of warm air and the onset of heavy precipitation, and

therefore be carried away from its moorings, as it were, and set adrift along the great air currents, where, as already stated, it acts as a travelling centre of vigorous interzonal circulation between middle and high latitudes. Of course, the very process that forces the storm away from its place of origin brings in colder air, usually from higher latitudes. But this, in turn, is slowly warmed from the great supply of heat in the water below, and thus all those conditions essential to the breaking off of another storm similar to the previous one are established, and so on indefinitely, or until the season and consequent temperature distributions so change as to prevent such action.

According to this conception, the permanent "low" around which interzonal circulation tends to be active often produces that local disturbance or deflection of the general circulation necessary to the genesis of a mechanical or dynamical cyclone. Further, although the necessary mathematical demonstrations may not be obvious, it appears in a general way that such a cyclone would travel a course and tend to exhibit characteristics as follows:

a. The storm would travel with the general circulation.

This is fully supported by observations.

b. It would tend, in general, to follow the path of maximum winds, this being the course approached by the west-to-east circulation, and therefore to travel along (not down, but at right angles to) the maximum interzonal temperature and pressure slope.

This inference is also supported by observations.

c. It would tend to follow normal annual isotherms.

This, too, is in accord with observations.

d. Because the winds to the east and southeast (northeast in the southern hemisphere) of the front generally are relatively warm and humid, and because they are focused in direction, thus leading to congestion that forces the rear winds to climb over those in front, it follows that, except as modified by topography and proximity to oceans, these would be the quadrants of maximum precipitation, as indeed they commonly are, except along west coasts.

e. The rising and, therefore, rain-producing air should flow off eastward with the general circulation.

The cirrus and other high level clouds that forerun the cyclone amply support this inference.

f. The mechanical cyclone should usually be accompanied by a correlative anticyclone to its rear.

There is much observational evidence in support also of this conclusion.

g. The average latitude of cyclones should be greater than that of anticyclones, since the main mass of air of the one has a component toward, and of the other from, the adjacent pole.

A statistical test of this conclusion is not at hand, but it seems to accord with inspection.

h. Since, as here conceived, the storm involves the general circulation from the surface to its top—that is, all the air up to the stratosphere—it seems possible that the pressure contrasts between " low " and adjacent " high " may also extend to this level.

Even this inference is supported by much observational evidence.[53]

i. Since, according to the conception here offered, the atmosphere of the particular type of cyclone under discussion is mechanically rather than thermally expanded, and since the swift winds of the front would tend to draw upward and out such air as leaks into the " low," it seems that the atmosphere of a cyclonic region might be warm in the east quadrant, but cold in the centre and other quadrants.

j. Since, according to this conception, the winds to the west of a cyclone are from higher latitudes, it follows that they must spread out, coming where meridians are more separated, with the upper portions flowing to lower levels, and also, because flowing toward the equator, must lag behind and thus by a damming up process build, or at least tend to build, a " high " in which the temperature of the bulk of the atmosphere, because of its downward component, shall be relatively warm.

[53] Dines, *Jr. Scot. Meteorol. Soc.*, **16**, p. 304, 1914.

k. The expansion of the lower air (below the stratosphere) in the "low" and compression in the "high" leads to lowering and warming the stratosphere over the cyclone, and raising and cooling it over the anticyclone. The difference in intensity of radiation by the moist and dry air of the two regions probably accentuates these conditions.

All the several inferences under *i*, *j*, and *k* (doubtful, because unsupported by analysis) are fully in accord with observations, whatever the physical cause or causes may be. This is shown by Figs. 16 and 17, which give respectively the vertical temperature gradients for winter and summer in regions of high (765 mm. and up), neutral (757.5 mm. to 762.5 mm.), and low (755 mm. and less) pressure, as determined by sounding balloons from Lindenberg, Munich, Strassburg, Trappes, Uccle, and Zurich. The figures of the legend give the number of flights from which the curves were determined. Abundant additional evidence of these formerly unsuspected temperature relations between the cyclone and anticyclone is given by Wagner,[54] Gold,[55] Dines,[56] and others. They must therefore be accepted as definitely established for the British Isles and Continental Europe, and tentatively accepted (until disproved if not true) for other parts of the world.

Probably the above conceptions of the mechanism of the average extra-tropical cyclone could be elaborately developed from the standpoint of hydrodynamics and thermodynamics, but this would be too tedious to include here. The concept, however, even without such support, may be useful in helping to remember the chief facts learned by recent free air observations.

"*Tropical.*"—As previously stated, a considerable percentage of the tropical cyclones (the actual number probably is only 2 to 3 per year in the northern hemisphere) migrate to extra-tropical regions. Shortly after recurving they gradually lose their original characteristics and become extra-tropical in type as well as location. Nevertheless, they generally still are called "tropical cyclones" (West India hurricanes, typhoons, etc.), however high

[54] *Beiträge zur Physik der freien Atmosphere*, 3, 57, 1909.

[55] "International Kite and Balloon Ascents," 1913. (Geographical Memoirs, No. 5.)

[56] *Jr. Scot. Meteorol. Soc.*, 16, p. 304, 1914.

the latitude actually reached. A causal name is not suggested for this cyclone, for the reason that it is not certain what is the chief factor in its origin.

As already explained, these storms originate usually, if not always, in the doldrums, where the air is quiet, hot, and excessively humid. The stillness of the air, if long continued, leads to a high degree of humidity, and the humidity, in turn, decreases the local pressure and also increases the absorptive power of the atmosphere for both solar and terrestrial radiation. Hence an inwardly directed pressure gradient and a corresponding circulation, the latter greatly facilitated wherever opposing trade winds exist, are slowly established. The resulting precipitation, through the latent heat thus set free, if sufficiently abundant and properly distributed, accentuates the circulation and thus secures the perpetuation of the cyclone until it fails for want of moisture, as it often does on dry land, or spreads and loses itself in the world circulation. As it recurves and gets well away from the tropics, it generally spreads out, becomes less intense, has most of its precipitation on the east side, and otherwise gradually acquires the characteristics of a cyclone of extra-tropical origin, and, presumably, is maintained in the same way. The physical cause of these storms, if they originate, as seems probable, in the doldrums and between counter trades or similar winds, appears to be partly thermal and partly mechanical, and their subsequent maintenance, after reaching the middle and higher latitudes, the same (largely mechanical) as that of any other cyclone of the same place.

ANTICYCLONES.

Anticyclones, or "highs," are divisible, with respect to their genesis, into two classes: (1) Mechanical: *a*, permanent, and *b*, migratory. (2) Radiational: *a*, permanent; *b*, semipermanent; and *c*, transitory.

In this classification the relative "high" that obtains over an entire hemisphere during its winter, and also those seasonal highs of continental (during winter) and oceanic (during summer) extent, have all been excluded. Like the lows of similar great size, they only modify somewhat the course of the general circulation and give direction to monsoon winds.

Mechanical (Permanent).—Since the surface of the ocean is a gravitational equipotential surface, it follows that west winds,

by virtue of their excess centrifugal force, will tend to climb up the bulge of the earth toward the equator, and east winds, because of deficiency in centrifugal force, will tend to slide down this bulge toward the nearest pole. Hence along the borders, between trade winds and the west winds of adjacent higher latitudes, the atmosphere must be subject to a mechanical squeeze. In other words, mechanically produced high pressure belts must encircle the earth at about latitudes 30° to 35° N. S. They must also be best developed over the oceans, where the trade winds, upon which they largely depend, are strongest and steadiest. These belts are clearly shown in Fig. 48.

Mechanical (Migratory).—The migratory anticyclone referred to here, and assumed to be generated in the manner explained in the discussion of mechanical cyclones, is the common one of middle latitudes. The directions of its system of winds, but in no sense the complete paths of the air particles, are given by synoptic charts. These directions are spirally outward, clockwise in the northern hemisphere, counter-clockwise in the southern. Hence the relation of anticyclonic wind velocity to horizontal pressure gradient is given by the equation,

$$\frac{dp}{dn} = v\left(2\,\pi \operatorname{sin}\varphi - \frac{v}{r}\right).$$

in which r is the radius of curvature, nearly, of the wind-path at the place considered, and the other symbols have the usual significance as previously given. From the negative sign it appears that for a given radius of curvature the possible wind velocity in a "high" is strictly limited, whatever the pressure gradient.

Velocity and Path of Travel.—The velocity and normal path of the migrating anticyclone are by no means as well known as those of the cyclone, except, perhaps, through the studies of Bowie and Weightman [57] in respect to those that cross the United States. However, the size, frequency, and velocity of travel of anticyclones are all roughly the same as those of similarly located cyclones. Furthermore, their most frequented paths, though, perhaps, generally beginning at higher latitudes over continents and running to lower over the oceans than the similar cyclonic routes, are roughly parallel thereto.

Just why these close relations hold is not certain. It may be

[57] *M. W. R. Supplement*, No. 4, 1917.

interesting, however, to note that they appear to support the above assumption that generally the migrating cyclone and its neighboring westerly anticyclone are correlative parts of a single great atmospheric disturbance.

Wind Velocity.—The actual velocity of the wind in the different quadrants of an anticyclone and at different elevations is given in the following table by Peppler,[58] based on a large number of observations made during 1903–1909, at Lindenburg; latitude,

Anticyclonic Wind Velocity in Metres per Second and (Miles per Hour).

	Altitude	Surface 122 m.	500 m.	1000 m.	1500 m.	2000 m.	2500 m.	3000 m.	3500 m.	4000 m.
South quadrant	Winter	4.43 (9.9)	8.48 (19.0)	8.82 (19.7)	8.68 (19.4)	8.60 (19.2)	8.92 (19.9)	9.71 (21.7)	10.14 (22.7)	10.97 (24.5)
	Summer	3.92 (8.7)	6.19 (13.9)	6.25 (14.0)	6.36 (14.2)	6.17 (13.8)	5.97 (13.3)	6.19 (13.9)	7.08 (15.9)	7.83 (17.5)
	Year	4.16 (9.3)	7.32 (16.4)	7.52 (16.8)	7.51 (16.8)	7.38 (16.5)	7.44 (16.7)	7.94 (17.8)	8.60 (19.2)	9.39 (21.0)
West quadrant	Winter	3.93 (8.8)	7.60 (17.0)	7.19 (16.1)	7.35 (16.4)	7.23 (16.2)	7.21 (16.1)	7.57 (16.9)	7.75 (17.3)	8.11 (17.9)
	Summer	3.39 (7.6)	5.26 (11.8)	5.41 (12.1)	5.18 (11.6)	5.28 (11.8)	5.39 (12.1)	5.20 (11.6)	4.74 (10.6)	5.04 (11.3)
	Year	3.74 (8.4)	6.51 (14.5)	6.38 (14.3)	6.35 (14.2)	6.34 (14.2)	6.38 (14.3)	6.46 (14.4)	6.32 (14.1)	6.65 (14.9)
North quadrant	Winter	4.21 (9.4)	9.69 (21.7)	9.54 (21.4)	9.78 (21.9)	10.19 (22.8)	10.69 (23.9)	11.59 (25.9)	12.29 (27.5)	14.43 (32.3)
	Summer	4.05 (9.0)	7.01 (15.7)	7.68 (17.2)	8.41 (18.8)	8.85 (19.8)	9.51 (21.3)	10.04 (22.5)	10.68 (23.9)	11.45 (25.6)
	Year	4.13 (9.3)	8.35 (18.7)	8.61 (19.2)	9.09 (20.4)	9.51 (21.3)	10.09 (22.6)	10.80 (24.2)	11.47 (25.6)	12.92 (28.9)
East quadrant	Winter	4.29 (9.6)	8.24 (18.4)	8.83 (19.8)	9.56 (21.4)	10.92 (24.4)	12.44 (27.8)	13.52 (30.2)	14.02 (31.3)	15.68 (35.1)
	Summer	3.92 (8.7)	5.88 (13.2)	6.42 (14.3)	6.55 (14.6)	6.98 (15.6)	7.54 (16.9)	7.31 (16.3)	7.83 (17.5)	8.28 (18.5)
	Year	4.06 (9.1)	7.01 (15.7)	7.57 (16.9)	8.00 (17.9)	8.89 (19.9)	9.93 (22.2)	10.35 (23.2)	10.86 (24.3)	11.91 (26.6)

52° 10′ N.; longitude, 14° 15′ E. Probably other mid-latitude regions have approximately the same anticyclonic wind velocities, but this is not certain, nor are there at hand sufficient data to determine the question.

Radiational (Permanent).—There are two extensive regions, Antarctica and Greenland, where the barometric pressure always is high. At each place the high pressure appears to be the result

[58] *Beiträge zur Physik der freien Atmosphäre*, 4, p. 95, 1911.

of the very low prevailing temperatures, which in turn are due in part to the great elevations and in part to the free and abundant radiation from the snow surface through the comparatively clear skies, kept generally free from clouds by the descent of the upper air induced and maintained by the vigorous fallwinds. That surface radiation is an essential factor in establishing and maintaining these low temperatures is obvious from the fact that air cannot flow down hill, as it does in these regions, unless it has a greater density and therefore lower temperature than the adjacent atmosphere of the same level. It is also obvious from the prevailing and excessive surface temperature inversions, in which, and because of which, those ice fogs that doubtless furnish much of the interior precipitation are so common.

It will be well to remember in this connection that snow, in addition to being an excellent reflector and, therefore, poor absorber of solar radiation, is also a good emitter of those long wave-length (12–15 μ) radiations appropriate to its temperature. In this way the low temperatures are maintained, not only during winter when air circulation and, to some extent, cooling ice supply the only available heat, but also during the long-continued insolation of summer.

The air drainage thus produced is manifest in those strong and persistent southeast or anticyclonic winds that characterize the climates of the border and all explored portions of Antarctica, except, of course, near the pole, and, presumably, therefore, of the whole continent. Similar, though less vigorous, anticyclonic winds also prevail over and around Greenland. Each of these great regions but especially Antarctica, by virtue of its strong and continuous refrigeration, obviously is exceedingly effective in its influence on the atmospheric circulation of its respective hemisphere. If there were no such extensive high and snow-covered areas in the polar regions, it is clear that our general circulation would be less vigorous and doubtless very different in many places.

Radiational (Semipermanent).—As is well known, there are five semipermanent "highs," all of which occur on the oceans: Two, as Fig. 48 shows, about 35 degrees north of the equator and three about 32 degrees south of it. Two are on the Pacific Ocean—one west of southern California, the other off the coast of Chile; two on the Atlantic Ocean—near the Azores (known as

the Azores "high") and off the coast of southern Africa; and one on the Indian Ocean, about half-way between Africa and Australia. A sixth oceanic "high" of this same class, but far less persistent than any of the above, often develops, especially during winter, in the region of the Bermudas.

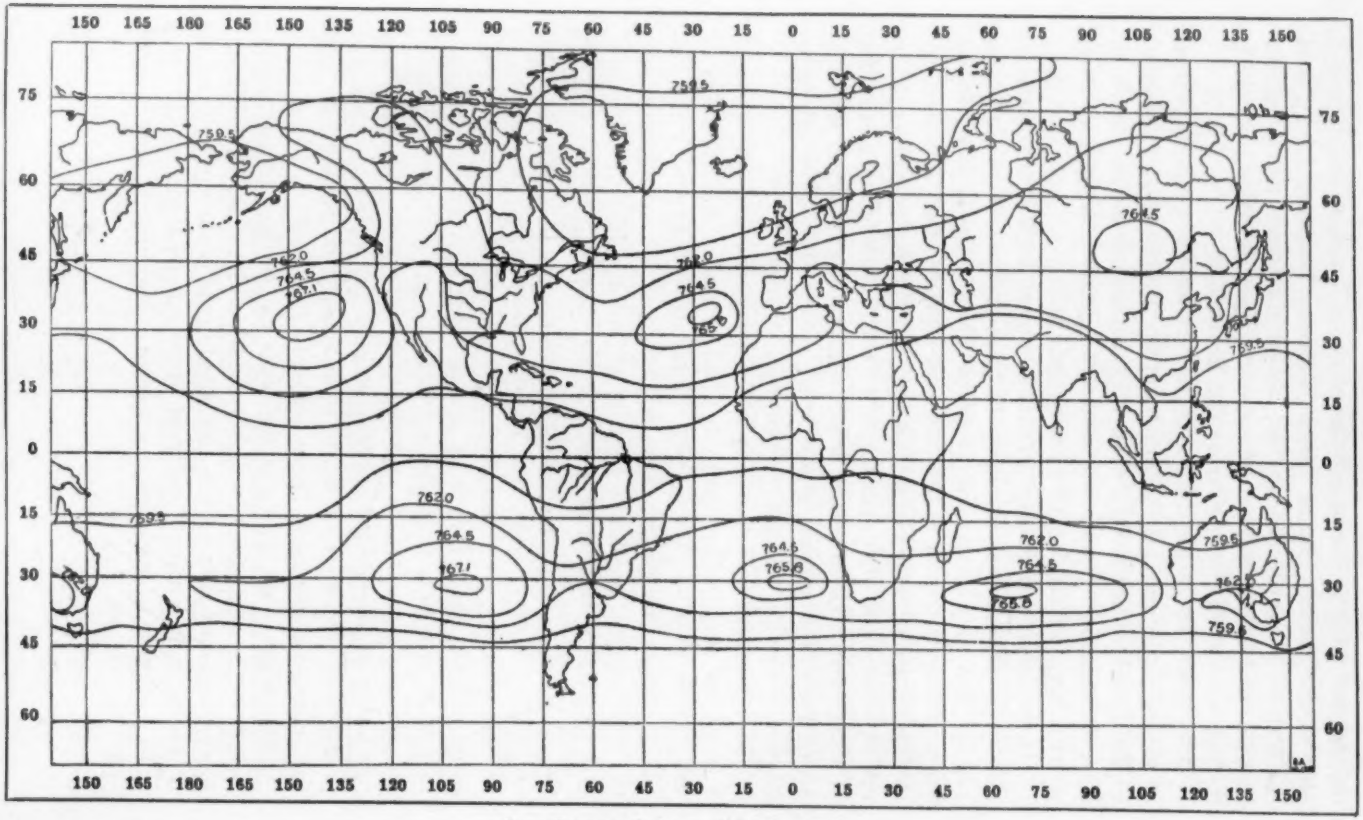
Obviously there must be a close relation between the intensities and locations of these highs and the directions and velocities of the surrounding winds, even to great distances, as shown by Figs. 49 and 50. Hence it is meteorologically important to form some conception in regard to their origin.

It will be seen from Fig. 48 that all these "highs" or centres of maximum pressure occur along the high-pressure belts, and from Fig. 51 that they occur at those places along these belts where the temperature of the air is low for that latitude; that is, where the isotherms are deflected equatorward. At these places, then, there are two causes of high pressure: (*a*) the mechanical pressure that produces the high-pressure belts, as already explained, and (*b*) a relatively low surface temperature which allows the upper air to cool somewhat and correspondingly contract.

It is known from sounding balloon records that the temperature of the atmosphere even to great altitudes follows more or less closely any long-continued temperature changes of the surface. Hence one might reasonably expect the atmosphere over the cold regions, as shown by Fig. 51, to be colder at every level than that of the surrounding atmosphere over warmer regions. A change of 1° C. throughout would change the pressure by 2 mm. or more. Hence, since the regions in question, according to Buchan's charts, are from 1° C. to 3° C. colder than those of the same latitude east or west, it appears that the pressure maxima of 2 mm. to 6 mm. probably are due to the continuous relatively low surface temperatures. In this case the "high" appears to be due to the cooling of the superincumbent atmosphere to that temperature at which its radiation is in substantial equilibrium with the minimum radiation from below.

But what is the cause of the local low surface temperatures? Referring to Fig. 52, it will be seen that there are five different places, and only five, where a distinctly cold ocean current crosses a belt of high pressure, and that every one of these is associated with a region of maximum pressure. Neither is there a semi-

FIG. 48.



Annual average isobars. (After Buchan.)

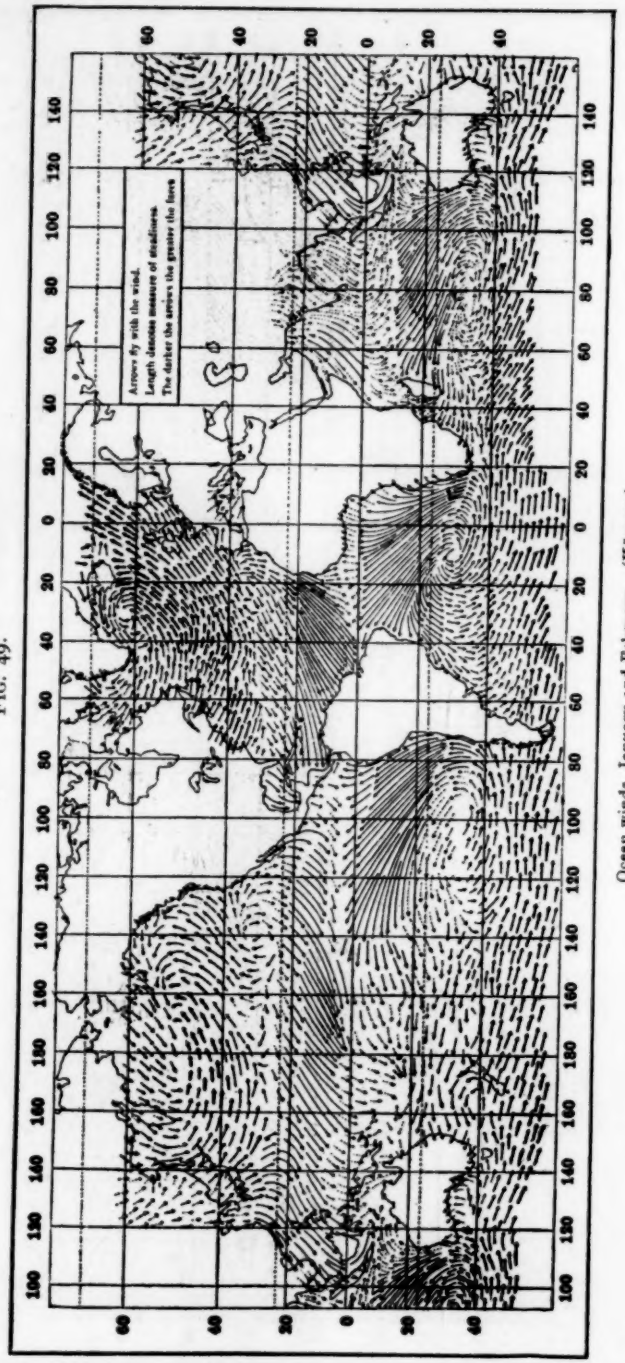


FIG. 49.

Ocean winds, January and February. (Köppen.)

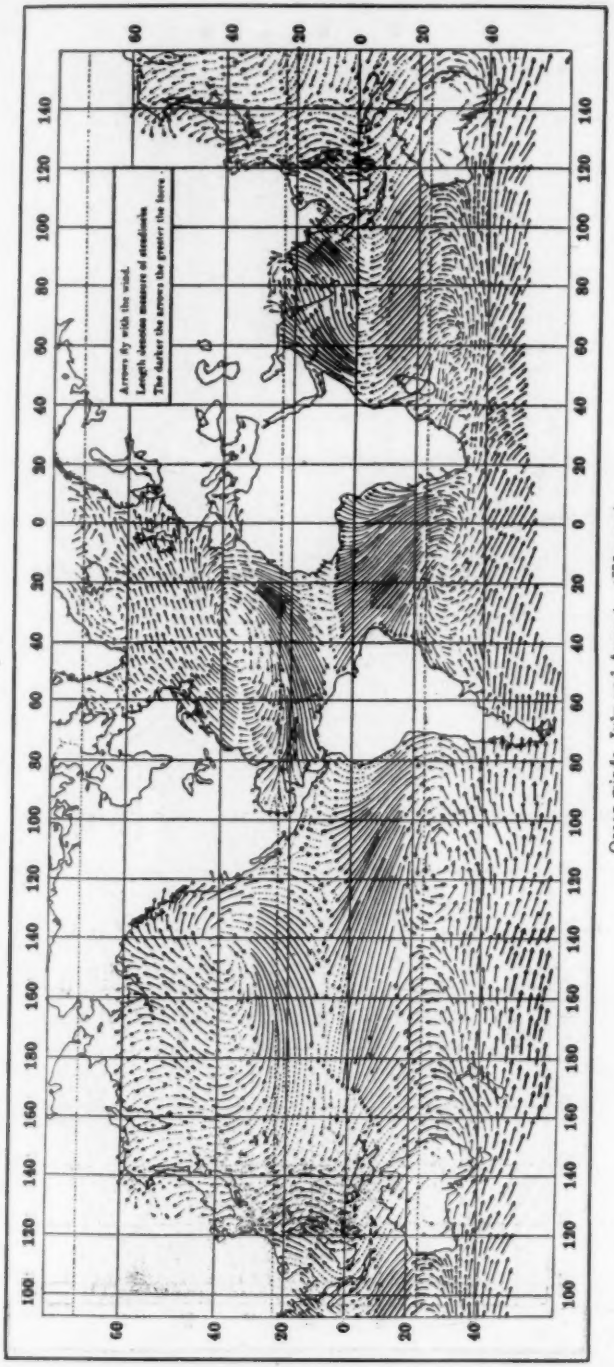


FIG. 50.

Ocean winds, July and August. (Köppen.)

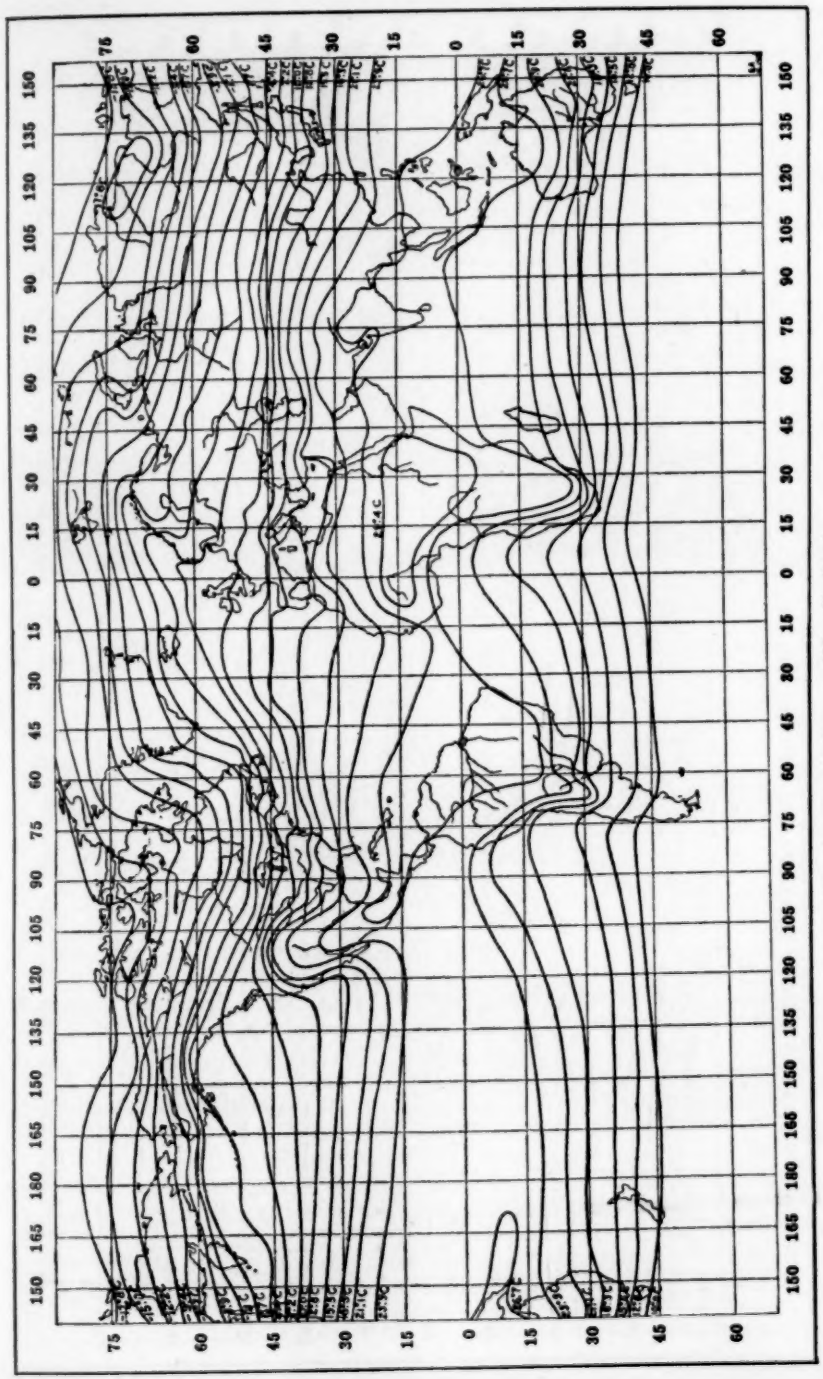


FIG. 51.

Annual average isotherms. (After Buchan.)

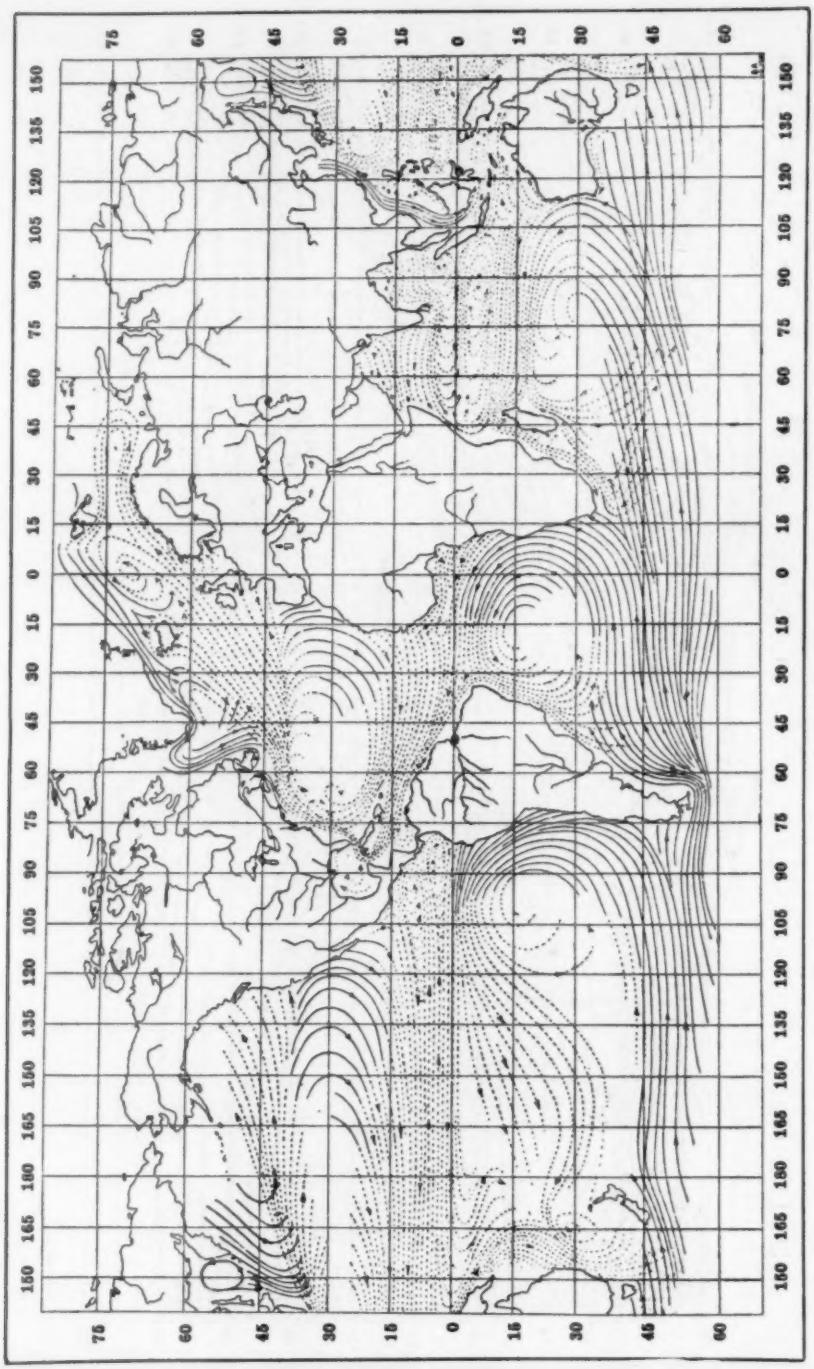
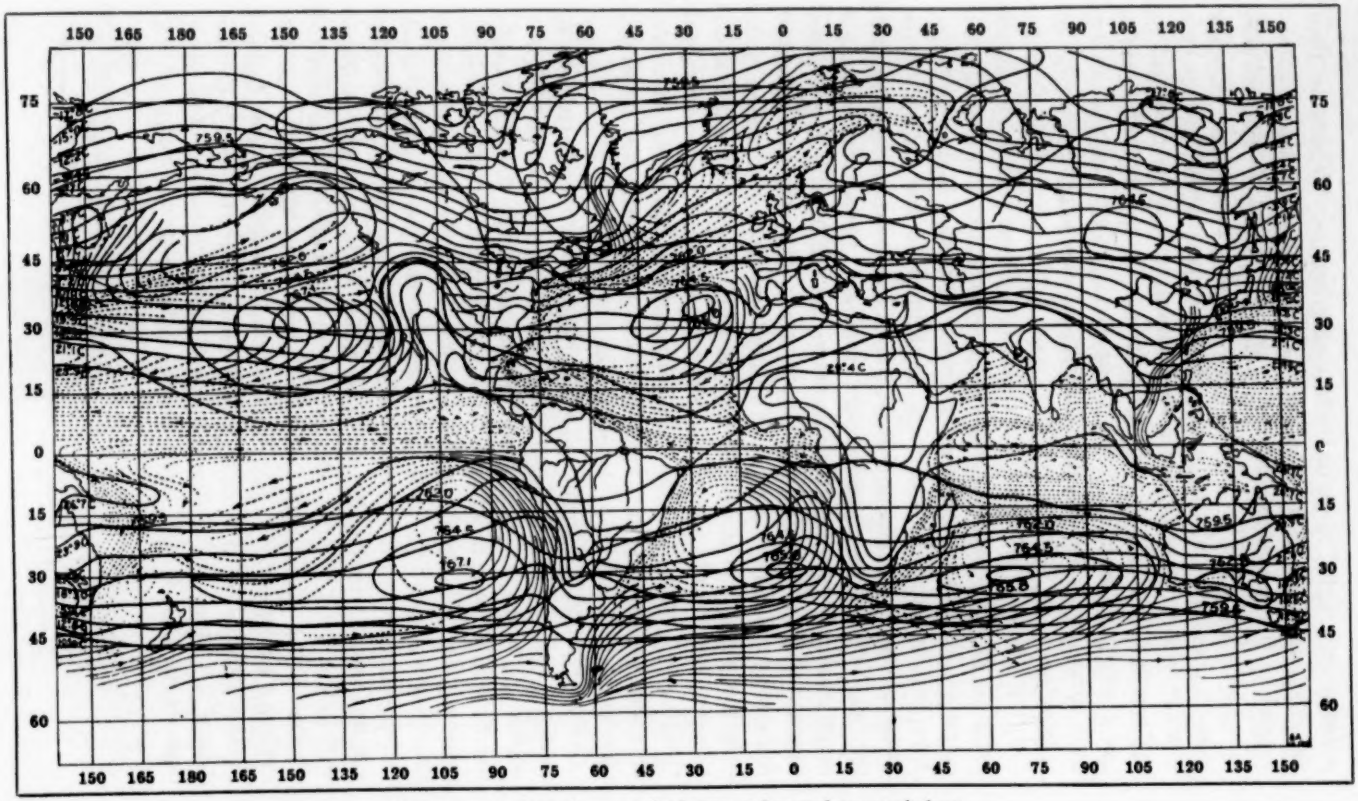


FIG. 52.

Ocean currents.

FIG. 53.



Ocean currents, annual average isotherms, and annual average isobars.

permanent " high " anywhere else on the oceans. Wherever, then, the mechanical effect that produces a belt of high pressure is reinforced by thermal contraction due to cold water, there, and only there, as illustrated by Fig. 53, are found a maximum of atmospheric pressure and the centre of a semipermanent anticyclone. During winter there is also a slight minimum temperature along the North Atlantic high-pressure belt near Bermuda, and a similar one along the South Pacific belt just east of New Zealand, and at each place a corresponding tendency to the maintenance of an anticyclone.

One obvious effect of all these semipermanent highs is the location of branches or channels of interzonal circulation, analogous to those of the cyclones and anticyclones of higher latitudes. Thus, much tropical atmosphere, in addition to that carried by the counter-trades, reaches middle latitudes by flowing around and to the west of the semipermanent " highs." From here the next stage in the general circulation takes the air to still higher latitudes, and even to polar regions, around and to the east either of the semipermanent " lows " or of the migratory cyclones. In its return it passes to the west of the " lows " or east of the travelling " highs," and finally around and to the east of the semi-permanent " highs." These, however, are only general channels and, presumably, average routes, upon which are superimposed innumerable and ever-changing irregularities.

Radiational (Transitory).—During winter elevated snow-covered regions often become very cold and thus build " highs " similar to those of Greenland and Antarctica, though usually much smaller in extent, as well as only temporary. Occasionally these give rise to strong and cold surface winds, especially when the existing gradient is accentuated by the passage of a well-developed cyclone along lower latitudes. Examples of such winds are the mistral of the Rhone Valley and the bora of the Adriatic and Black Seas. The Texas norther and, probably, the blizzard of the Great Plains are other and important examples of the drainage of transitory radiational anticyclones. The well-known violent fallwind of the coast of Norway appears to have a similar origin, as indeed have innumerable other drainage winds in all mountainous and high plateau regions outside the tropics.

FORCED WINDS.

Although in greater or less measure all winds are interdependent, only a relatively small number obviously are generated and maintained by other and coexisting winds. Among these are eddy winds, foehn or chinook winds, and, presumably, the winds of the tornado and waterspout.

Eddies.—Wherever the wind blows across a steep-sided hill or mountain, eddies are likely to be formed, especially on the lee side. In such cases the direction of the surface wind is approximately opposite to that of the general or prevailing wind, with a calm between them.

For the practical purpose of the weather forecaster, wind eddies have but little significance, except in one important particular. He must exclude from his forecasting data all reports of wind direction obtained at places where eddies are likely to prevail. Such eddies, however, may be of great importance to the aviator, since they produce, on their forward sides, troublesome down-currents and also shallow surface winds which, because oppositely directed to the winds, less, perhaps, than 100 metres above, may render landing at such places difficult or even very dangerous.

Foehn, Chinook.—The foehn, or chinook, as it generally is called in North America, is a warm, dry wind blowing down a mountain side onto the valleys and plains beyond. It differs from the typical fallwind in being warm, level for level, and not cold, as is the latter, in comparison with the air of surrounding regions.

Any system of winds, whether of trade, cyclonic, or other origin, extending to or near to the surface and blowing more or less normally across a mountain ridge, necessarily induces up-currents, dynamically cooled, on the windward side and down-currents, adiabatically heated, on the lee side, except along the under portions of such eddies as may be produced, where the directions and consequent temperature changes are just the reverse. Therefore:

1. Foehns occur at all seasons.
2. The relative humidity of the foehn is always low.
3. The rise in temperature is greatest when the original vertical temperature gradient is least; hence greatest, other things being equal, *a*, when the upper air is warmest—that is, when there has been precipitation to the windward; *b*, when the surface air is

coldest—that is, when there has been free night radiation (clear skies) on the lee side; and *c*, during winter, when the vertical temperature gradient through the first several hundred metres may be only 4° C., say, per kilometre, instead of the usual 7° to 8° C. of summer.

Since foehn winds often are swift and the heating rapid, it follows that the most pronounced of them are quite likely to be accompanied also by frequent but irregular convections and, therefore, strong gusts, swirls, and general turbulence. Under favorable conditions a foehn may even develop a secondary "low," the primary, of course, being on the same side of the mountain.

TORNADO.

The tornado,[59] in which the air travels in approximate circles, as its name implies, is well nigh peculiar to the United States east of the Rocky Mountains. Nor is it at all equally distributed over even this area, since it occurs rarely in the Alleghenies, seldom along the Gulf and Atlantic coasts, frequently in central and northern Alabama, Georgia, and South Carolina, frequently also in Ohio, Indiana, Illinois, and southern Michigan, and most frequently in Missouri, Kansas, and Iowa.

The tornado develops only in connection with a thunderstorm, usually just in front of the rain, and especially in connection with those particular storms that form along a valley "low," or between V-shaped isobars where opposing winds of widely different temperatures give rise to that exceptionally strong vertical convection essential to the genesis and growth of the thunderstorm. The season of most frequent occurrence, therefore, is spring and early summer; in fact, during winter it is unknown, except occasionally near the Gulf and in other warm sections. Similarly, the time of most frequent occurrence is 3 to 5 P.M. Also, since it is only a local phenomenon, while the conditions favorable to its genesis are much more extensive, it often happens that a number of tornadoes develop, even close together, in connection with a single distorted cyclone.

The diameter of the tornado averages only about 300 metres (984 feet); the length of its path varies roughly from 100 metres to possibly 500 kilometres (328 feet to 310 miles); its direction of

[59] For detailed discussion see: Finley, "Tornadoes," New York, 1887, and Ferrel "A Popular Treatise of the Winds," New York, 1889.

travel is nearly always northeast; its rate of travel, though differing greatly, averages roughly 11 metres per second (25 miles per hour), thus passing a given place in half a minute or less; while its winds, always counter-clockwise, are the swiftest known, estimated at 45 to 225 metres per second (100 to 500 miles per hour). It is therefore by far the smallest, briefest, and severest of all storms. Essentially it is a phenomenon of the middle atmosphere. In its genesis clouds whirl around each other with great velocity and turmoil, while from beneath their centre a funnel-shaped cloud develops, usually tapering off to a long pendent spout that may or may not extend to the earth. Wherever it does reach the surface it produces a deafening roar, and practically everything in its immediate narrow path that can be blown down or torn to pieces is destroyed, though generally but little damage is done on either side. On the other hand, wherever it does not come to the surface its passage produces but little or no effect.

Cause.—From the characteristics of the tornado and from the meteorological conditions that normally accompany it, it appears that its origin must be purely mechanical. Thus its rotation obviously is derived essentially from that of the cyclone in which it occurs, since it is always in the same sense, counter-clockwise, however small its diameter, and never clockwise, as is often the case with large dust-whirls when formed in still air. But how is the rapid rotation started? From the directions of the V-shaped isobars it is clear that at a kilometre or so above the surface there must be neighboring winds flowing in approximately opposite directions and, of course, more or less intermingling and overrunning counter currents. Hence, under such conditions, the inflow occurring at various levels that feeds the strong up-draft always just in front of a thunderstorm must occasionally so deflect these counter currents and bring them so closely together as necessarily to produce a violent whirl.

Here, too, as in all other cases of atmospheric motion, the law of the conservation of areas, or the constancy of the product of radius of curvature by linear velocity, applies, except as modified by friction and viscosity. Hence, as the radii of curvature of the opposing currents may at first be comparatively large, and after the deflection relatively small, it follows that the wind velocity within the whirl, in which both the counter currents are

taking part, may be very great. This rotation, however, does not check the up-current, hence that convection which is essential, as explained above, to the rotation is maintained, and therefore the rising currents brought in spirally with increasing angular and linear velocity as the axis of spin is approached. Each filament, so to speak, of the spirally rising air viscously drags along its under and slower neighbors, thereby bringing them nearer the axis and increasing their velocity. In this manner the whole of the rising column is set whirling with greater or less spin. Around the axis of rotation the pressure obviously is reduced in proportion to the centrifugal force, the temperature correspondingly lowered, and therefore a cloud spout often formed.

Wherever the inflow of the surface air is greatly checked, or its course so altered by a deflecting hill or other obstacle as greatly to decrease the spin, there the tornado must lift. It may, however, retain its full vigor in the unaffected upper air, and soon reach the surface again.

Why Essentially Peculiar to the United States.—Since the tornado rarely occurs in violent form except in that portion of the United States which is east of the Rocky Mountains, it follows that that combination of meteorological conditions essential to its genesis seldom obtains in other parts of the world. This combination appears to be very simple—only a vigorous convection between strong neighboring counter currents. But since vertical convection, as indicated by thunderstorms, is common enough in most parts of the world, it follows that the other factor —namely, strong counter currents—is the distinctly American phenomenon. That such currents should often occur east of the Rocky Mountains is obvious from the position and trend of these mountains themselves, giving rise to southward winds, and the location of the Gulf of Mexico, from which winds turn northward. No other similar combination of mountain and ocean wind controls exists, and therefore no other place has in all respects the same kinds, frequencies, and intensities of storms.

Waterspouts.—Only its well-established name requires that the waterspout shall be specifically mentioned, since mechanically it does not differ essentially from the tornado. In fact, a tornado becomes a waterspout as soon as it passes to sea, while a waterspout becomes a tornado immediately it invades the land.

The waterspout, like the tornado, originates well up in the

atmosphere, and is especially frequent in those regions where adjacent winds, usually the one above the other, have different directions; hence where the counter trades, overrunning the trades, occur at ordinary cloud or convection levels; along the belt of doldrums, when considerably removed from the equator and flanked by opposing trade winds; and along boundaries of sharp temperature contrasts, such as the northern border of the Gulf Stream. In all such regions vertical convection may induce a more or less violent whirl in the same manner as that explained in the discussion of the tornado.

Occasionally small whirlwinds start from the surface of lakes or other bodies of water during calm hot weather. The strongest of these produce cloud columns, due to expansion, and are often called " waterspouts," though of radically different origin from that of the waterspout above described.

(To be continued.)

Reinforced-concrete Building with 2000-pound Floor Load. ANON. (*Engineering News-Record*, vol. 79, No. 23, p. 1065, December 6, 1917.)—Floor loads of 1000 and 2000 pounds per square foot as a maximum and 600 pounds as a minimum are an unusual condition provided for in the design of a reinforced-concrete warehouse and factory building now being erected in Chicago. These exceptionally heavy loads are due to the storage of steel plates and bars, while the lighter load is to provide for the reaction due to the operation of large punch presses. The building is approximately 45 x 75 feet, with five stories and a basement.

The heaviest loading will be for a width of 12 feet along one side of the second story where steel bars will be stored. This portion of the floor, about 33 per cent. of the floor area, is designed for a load of 2000 pounds per square foot. Support is provided by 12-inch concrete partition walls which are built on foundation girders and extend to the bottom of the heavily-loaded portion of the second-story slab. In the basement and the first story these walls are utilized to support racks for the storage of steel rods. The racks are composed of rows of heavy pipes embedded in the walls and projecting 18 inches on each side. The remaining 67 per cent. of the second story and the entire area of the first story are designed for a load of 1000 pounds per square foot. The three upper floors are designed for 600 pounds per square foot. The foundation, a concrete slab laid directly upon the clay, is surmounted by girders running in both directions. The interior columns are located at the intersections of these foundation girders.

Mazda Lamps for Motion-picture Projectors. L. C. PORTER. (*General Electric Review*, vol. 20, No. 12, p. 979, December, 1917.)—For a long time it was thought impracticable to apply incandescent lamps to large motion-picture projectors, and the arc lamp has had the field to itself. There were several reasons for this. The crater of the arc in common use as a light source for motion-picture projectors operates at about 130 candle-power per square millimetre; whereas the tungsten filament of a Mazda lamp at the melting-point emits only 79 candle-power per square millimetre, and at practical operating temperatures about 34 candle-power per square millimetre. Further, the condensers in common use utilize a solid angle of light of about 32 degrees. This angle includes a high percentage of the light flux from an arc due to the light distribution characteristic of the arc, whereas with the nearly spherical light distribution of the Mazda lamp this becomes a small proportion of the available light flux. Again, the crater of the arc is a relatively solid homogeneous light source, and an image thereof projected upon the screen results in fairly even illumination, while with a Mazda lamp an enlarged image of the filament is projected, resulting in a very streaked screen.

These obstacles, though seemingly great, have been overcome. The enormous difference in brilliancy of the two sources was lessened by developing a new type of Mazda lamp and a new lens system. Of these components, the condenser plays the most important part in solving the problem. It was found impracticable to make a plano-condenser of sufficiently short focus. The difficulty was overcome by the design of a condenser somewhat similar to a semaphore lens; that is, a lens with steps or corrugations. With this condenser a solid angle of 75 degrees was intercepted, which immediately resulted in a very large increase in the light flux available. A further gain in illumination was obtained by the use of a spherical mirror placed back of the light source. This arrangement of condenser and mirror practically increased the useful angle to 150 degrees. The corrugations on the condenser also performed the useful function of breaking up the filament image, resulting in an even screen illumination.

Many types of lamps were tried, and the one chosen is provided with a filament consisting of four helices contained within a space 0.4 inch square and has a capacity of 750 watts at 30 ampères. With this current high brilliancy is secured with a life of 100 hours. A compensator with either a rheostat or a reactance control in the primary is employed to accurately control the current value, and so maintain the high efficiency without diminishing the life of the lamp by accidental increase of current. The 750-watt lamp replaces any alternating-current arc on the market and direct-current arcs up to 40 ampères, and will project pictures 12 feet wide on a white plaster or cloth screen, or 16-foot pictures on a metallic, fibre, or glass screen. A large reduction in operating cost as compared with arc lamps and better pictures are obtained.

MECHANICAL DIFFERENTIATION.*

BY

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At first thought it would seem that mechanical differentiation is simply a reversal of mechanical integration, and that any instrument having the latter function might also be used for the former. A modicum of reflection will show, however, that the two are not necessarily even complementary. Differentiation with a planimeter would be impossible. As is well known, that instrument finds its main use in the evaluation of irregular areas. Its dial reading is meaningless until the tracing-point has returned to the starting position, when the reading stands for the summation of infinitely small rectangular strips swept over by the planimeter arm. This summing up of infinitesimal areas is exactly what integrating means. Differentiation, on the other hand, is the process of evaluating the rate at which one dependent variable changes with respect to a second independent variable, and no stretch of the imagination can conceive of a planimeter, the simplest piece of apparatus for integrating, being used for this purpose.

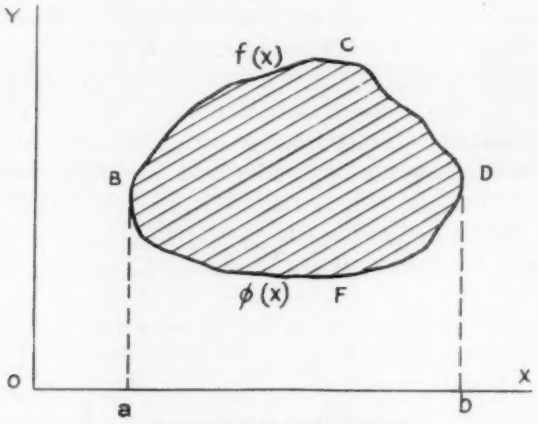
Any area whatsoever may be looked upon as a surface bounded by a closed curve, in which the curve shows the relation between two variables plotted upon coördinate axes. Or it may be regarded as the difference of two areas, as, for example, in Fig. 1, where the shaded area is the difference between the two areas *aBCDb* and *aBFDb*. Inasmuch as the two curves $f(x)$ and $\phi(x)$ do not coincide, they follow different laws, so that the planimeter reading is really the difference between the two definite integrals $\int_a^b f(x)\,dx$ and $\int_a^b \phi(x)dx$. The fact that the planimeter deals with definite integrals of this kind only renders it worthless for differentiation.

Other integrating machines exist, however, that are not limited in this way. The most notable of these is the Coradi integraph, an instrument well known in the scientific world for its remarkable accuracy and mechanical perfection. It, and instruments of its kind, record areas as a continuous process by

* Communicated by the Author.

drawing a curve in which each ordinate distant x from the origin represents to some scale the area under the given curve up to the corresponding ordinate. In Fig. 2 $F(x)$ is the given curve. It may be empirical or theoretical. If it be traced with the point of the integraph by starting at a and proceeding in the clockwise direction up to A, then through B and b back to a, the recording pen will trace a curve $\theta(x)$ similar to that shown below. In going from a to A with the tracing-point, the recording pen stays in position on the x-axis, but immediately upon leaving A the latter begins to rise and move forward with the tracing-point, its motion being controlled by a parallel mechanism in such a way

FIG. 1.



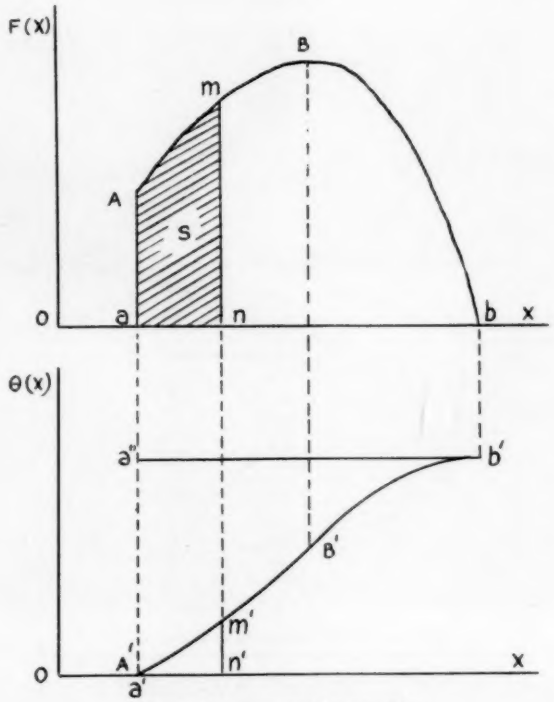
Integration with the planimeter.

that any ordinate $m'n'$ distant x from the origin represents the area S, limited by the corresponding ordinate of the given curve. In other words, the integraph and other instruments like it evaluate the integral $\int_a^x F(x)\,dx$.

Having followed the development of the so-called integral curve, we are in a position to consider the inverse operation; namely, that of obtaining the derivative curve of a given curve. Mechanical differentiation means nothing more than the drawing of the derivative curve of any experimental curve. Such a curve is shown in Fig. 2, for example, by ABb. Each ordinate of this curve represents to some scale the rate $\frac{dy}{dx}$, for the corresponding point on the given or primitive curve below it. Inasmuch as the

derivative, $\frac{dy}{dx}$, at any point is shown graphically by the slope of the tangent at that point, it is obvious that the derivative or rate at A' is not zero. It is shown in the derivative curve by Aa. At B', the point of inflection, the slope is a maximum, and at b' the primitive curve is horizontal, hence $\frac{dy}{dx}$ is zero and the derivative curve has come down to the x-axis. For the rest of

FIG. 2.



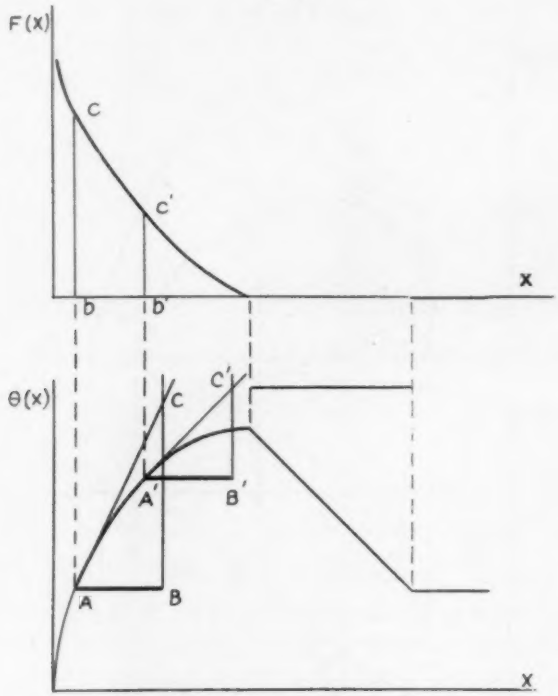
Derivative curve and its primitive.

the path from b' to a'' the gradient remains zero, and the derivative curve here coincides with the x-axis.

A straight line making any angle with the horizontal has the same slope at all points along its length, hence its derivative curve is a straight line parallel to the x-axis. Any other straight line making a different angle with the horizontal would be represented by a line parallel to the x-axis at a distance greater or

less than that of the first, depending upon its slope. The derivative curve for two such lines intersecting each other would consequently show a discontinuity at the point of intersection, so that for this particular point of the primitive curve the recording point would have to assume two positions. It is seen thus that any instrument for mechanical differentiation must provide for

FIG. 3.



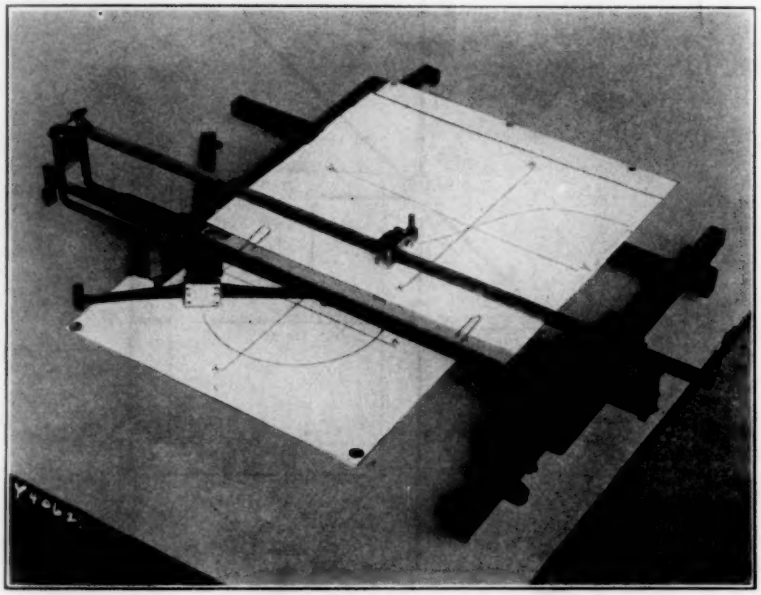
Method of obtaining the derivative curve.

the two possible relative motions, one a horizontal motion of the recording-point while the tracing-point suffers both vertical and horizontal motion, and a second in which the recording-point may receive a vertical motion while the tracing-point remains in position but is rotated. With these two difficulties overcome, there still remains the necessity of a means for accurately determining the direction of the tangent at every point along a curve. The kinematics of the instrument once solved, it will be found that

usually a number of devices for orienting or locating the tangent may be used on the same machine.

While the method for obtaining the tangent at any point on a curve may seem of secondary importance, it is really very pertinent, since the accuracy of the machine is determined almost entirely by the accuracy and practicability of the orienting device. Five ways for drawing a tangent to a curve seem thus far to have been developed, any one of which may be applied by the

FIG. 4.



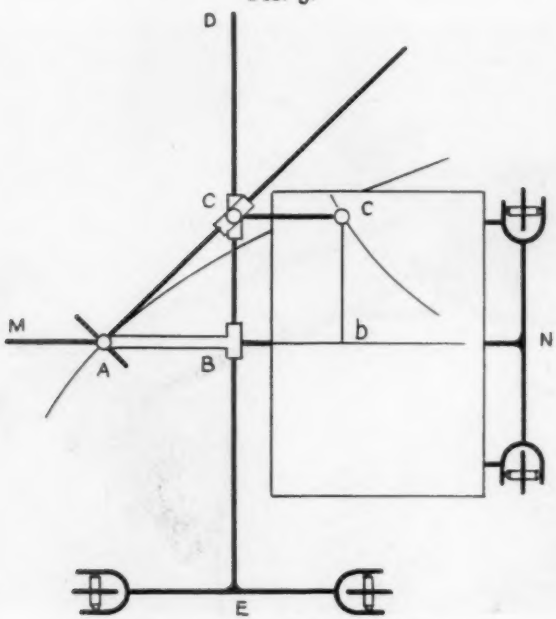
The author's first differentiating machine.

designer of a differentiating machine to his problem. One of the first actually tried in mechanical differentiation was that of Professor J. Erskine Murray,[1] who used two small dots upon a sheet of celluloid at a distance of two millimetres apart. By placing this flat upon the drawing and turning it until the two dots just touched the curve, the tangent at this point of the curve coincided with a line drawn through the two dots. Somewhat similar to this is the means used in the attachment to the integraph

[1] *Proceedings of the Royal Society of Edinburgh*, 1904, p. 277.

for differentiating, by two ruled lines at right angles on a piece of glass which is placed upon the curve until one of these is tangent and the other normal to the curve at their point of intersection. A third and more common means for drawing the tangent is by locating the normal first, through the reflection in a mirror set vertically upon the drawing. When the curve and its image form a continuous smooth line without a cusp at their juncture the mirror is normal to the curve. To obtain a continuous record

FIG. 5.



Skeleton illustrating the Author's first machine.

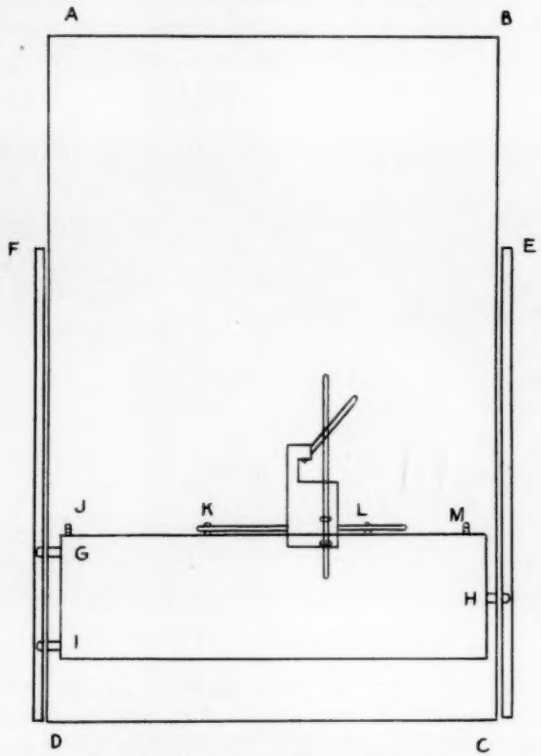
of the tangent, possibly the sharp disk is the most feasible. In coursing the curve with a small disk of this kind the tangent is continually maintained by the plane of the disk so long as the latter follows the curve. A fifth device is that of Guillery's[2] "aphegraphe." It depends for its accuracy upon the skill with which the operator can fit a metal strip or batten to the curve. A very thin lip of metal slipped into a suitable cut made at right angles to the face of a piece of mica completes an electric

[2] *Mem. Soc. Ing. Civ. de France*, April, 1911.

circuit when by rolling the mica upon the batten, the lip, which is flush with the mica, comes in contact with the batten. The face of the mica is then tangent to the curve at the point of contact of the lip with the batten.

Having decided upon the device for locating the tangent, the next step in the design of a differentiating machine is the selection

FIG. 6.



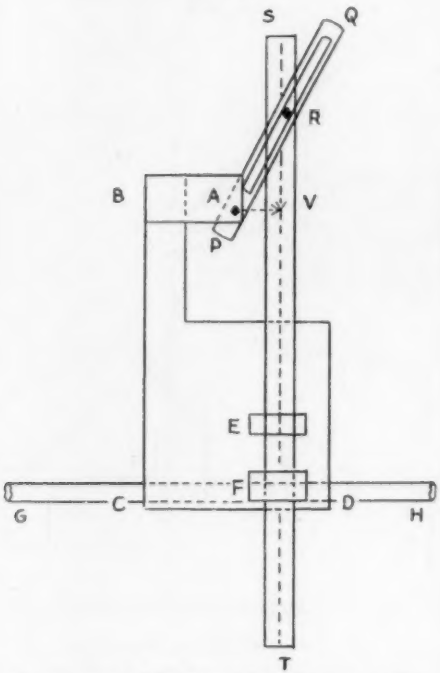
J. Erskine Murray's differentiating machine.

of a tangent base of constant length. In Fig. 3 such a base is shown by the two heavy horizontal lines AB and $A'B'$ of equal length. If this is the unit of measure, then the vertical distances BC and $B'C'$ intercepted by the tangents at A and A' directly measure the magnitude of the slope at these two points. The problem for the designer is the transferral of these distances mechanically to a suitable set of coördinate axes; for they also

measure the derivatives at the respective points, since slope and derivative are identical. The resulting curve would then be the desired derivative curve. In the example cc' is the derivative curve of the primitive AA', with bc equal to BC, and $b'c'$ equal to $B'C'$.

These problems have all been met in a limited way by the author's first differentiating machine, shown in Fig. 4.[3] The

FIG. 7.



Transverse carriage of Professor Murray's machine.

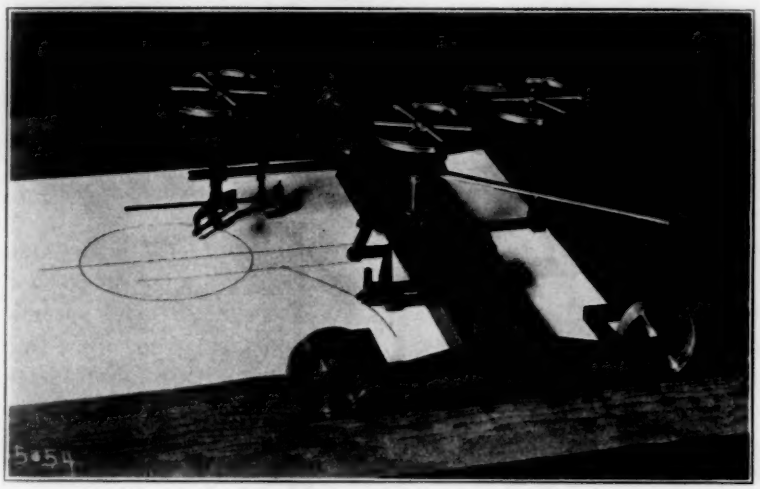
various kinematical relations of this instrument are shown in the skeleton machine of Fig. 5. The mirror and the image of the curve are plainly visible in the first figure. In Fig. 5 the mirror is normal to the given curve at A. Two carriages are provided, running in grooves at right angles to each other. One

[3] For a detailed description of the differentiating machine, see *Scientific American Supplement* for February 12, 1916, or the *American Mathematical Monthly* for October, 1916.

of these carries a plate upon which is fastened the sheet of paper to receive the derivative curve. The link *AB* may move vertically along the bar *DE* and horizontally along the bar *MN*, fixed to the second carriage. The tangent base or link and the derivative curve are lettered to agree with the letters of Fig. 3.

Somewhat similar ideas are embodied in the instrument of Professor J. Erskine Murray, shown in Fig. 6.[4] The board *GHI* moves vertically in the side grooves *DF* and *EC* and carries the sheet of paper upon which the derivative curve is to be placed. The sliding rod, shown to a larger scale in Fig. 7 as *ST*, carries

FIG. 8.



The Author's latest differentiating machine.

the recording pencil. The distance *RV* measures the derivative, and *AV* is the tangent base. The carriage *BD* may move horizontally in suitable guides fixed to the board *GHI* of Fig. 6.

Both machines described embody several undesirable features. First among these is the fact that the derivative curve must be drawn "point-by-point," necessitating a supplementary filling in with a pencil; secondly, the derivative curve is placed upon a different sheet of paper from that of the given curve; and, thirdly, motion is not constrained in the reverse direction, so that integra-

[4] Reproductions are the original drawings published in the *Proceedings of the Royal Society of Edinburgh*, 1904.

tion to check accuracy is impossible. It was with the view of eliminating these three disadvantages that the author reverted to the " integrating roller " so successfully used in the Coradi integraph for graphical integration. Final developments led to the construction of the machine illustrated in Fig. 8. Many structural features embodied in the integraph were used in its design on account of the long period of evolution of that instrument and its unqualified success for graphical work. To overcome the lost

FIG. 9.

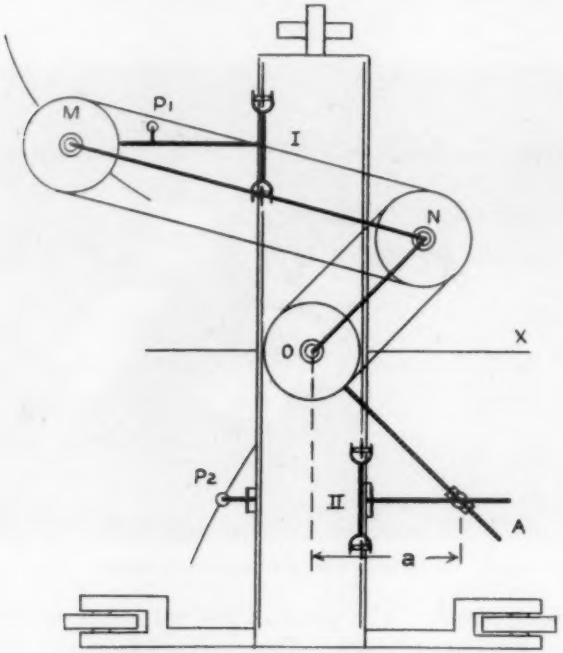


Diagram of the Author's latest machine.

motion due to the peculiar hanging construction of the parallel mechanism of the integraph when reversed for differentiation, the system of three pulleys connected with a continuous wire was resorted to. On account of the need for extremely easy running conditions, the third point of support was removed from the differentiating carriage by using three running rollers, and the carriage was balanced to eliminate all side thrust that might introduce friction.

The instrument is shown diagramatically in Fig. 9. By means of the parallel mechanism of three pulleys, the tangent bar OA is always kept parallel to the plane of the small steel disk with which the given curve is traced in differentiating, and which serves to give direction to the recording pen when integrating. Pulley M and the frame upon which the disk is mounted are both fixed to the same vertical shaft, so that this serves as the axis of rotation for the plane of the disk while rounding a curve. N is merely an idle pulley necessary on account of the variable distance from M to O. The distance a is the base or tangent constant. It may be changed by shifting the pivot on the arm extending out from the differentiating carriage II. An arm extends underneath the body of the machine from this carriage to the recording pen P_2 of Fig. 9, which draws the derivative curve of the curve followed by the steel disk. For integration, P_2 serves as a tracing-point and a pen attached to carriage I, shown as P_1, draws the integral curve.

While some difficulty attaches to the accurate tracing of the given curve with the disk, especially for the novice, the results obtained by the author when working slowly would substantiate a claim for the machine as being practical for drawing a continuous derivative curve. The tracing disk could also be removed and a mirror attachment added, or a ruled glass plate might be used similar to that described in the latest Coradi catalogue as an attachment for differentiation with the integraph by the point-by-point method.

On account of the uncertain mail delivery at the present time, it has not been possible to procure illustrations of the integraph attachments mentioned. The following quotation, taken in full from the catalogue of the famous Zurich firm, must therefore suffice as a description: "Device for differentiating, consisting of a cylindrical pin which fits in the sleeve of the drawing pen and carries a glass plate with engraved cross-lines which rests upon the plane; these cross-lines must be parallel to the X- and Y-direction, respectively, when the guide carriage [carriage to which the tracing point is attached when integrating, corresponding to the differentiating carriage of the author's machine] is in its normal position [the position for zero slope]. The pin fitting in the sleeve of the drawing pen is connected with the frame of the integrating roller by means of a parallelogram, so that when moving the guide carriage one of the cross-lines is always parallel

to the plane of the integrating roller and to the direction rule. If a curve is to be differentiated, the cross-line is so placed on the curve by means of the guide carriage that the cross-line parallel to the direction rule is always parallel to the elements of the curve in question.

"Device for differentiating as described above, but having instead of the cross-lines a reflector resting vertically on the plane; this must always be rectangular to the *X*-line when the guide carriage is in its normal position, a proof of which is that the reflection of the *X-line* forms a straight (uninterrupted) continuation of the same. If a curve is to be differentiated, the mirror is so placed on the curve by means of the guide carriage that the reflection forms an uninterrupted continuation of the curve in question. The differential curve is, however, not traced by means of a continuous line, but by making dots at suitable distances with the tracer point of the guide carriage and afterward connecting these by hand with a pencil."

NOTE.—The author wishes to express his gratitude to the Department of Mathematics of the University of Wisconsin for its generosity in financing the construction of the instruments described in this paper.

MADISON, WISCONSIN, September, 1917.

Torpedoes. (*Bulletin of the New York Public Library*, vol. 21, p. 657, October, 1917.)—In the search for a method of defence against the highly developed and effective submarine torpedo, with whose destructive possibilities we are only too well acquainted, one of the first essentials to success is a thorough acquaintance with the state of the art. Quite recently much valuable bibliographical work has been done in this field, notably by Miss Helen Hosmer, whose contribution was published in the August, 1917, number of the JOURNAL, and Mr. David Rushmore, in the paper appearing in the *General Electric Review* for July, 1917.

Latterly the New York Public Library has taken up this work, and there appears in its monthly bulletin a most comprehensive chronological bibliography on torpedoes. The list includes devices from the earliest times to the present. With the unusual facilities afforded by this splendid library the list is undoubtedly the most complete at present available, and it should be in the hands of all those who are making a serious effort to find a solution of a critical problem of the hour.

A GRAPHICAL METHOD FOR THE CONSTRUCTION OF ELECTROSTATIC FIELDS.*

BY

SYLVAN J. CROOKER.

THE METHOD.

THE force at any point of an electric field is equal to the difference of potential dV divided by the distance ds' from an equipotential surface measured along the line of force.

$$F = dV/ds'$$

In constructing an electric field we make use of the fact that the lines of force and the equipotential lines are an orthogonal system. For any arrangement of conductors in a homogeneous medium the approximate form of the field may be drawn by guess. The method used here is only applicable in checking up and correcting the approximately drawn field.

Measurements are made from the approximate drawing for the ds' distances between any two equipotential lines, one of which is used as a base line. Assuming that $dV = 1$ between these two equipotential surfaces, the force equation then becomes

$$F = 1/ds'$$

For each point along the equipotential line find F by using the reciprocal values of ds', and plot the *Force*-curve as shown in Fig. 1.

If now we integrate the area under the *Force*-curve, for example from o to the line AB, by means of a planimeter or other device, we get a value B for the definite potential integral,

$$V = \int_0^s F ds$$

Integrating to another point C on the *Force*-curve a value D on the *potential*-curve is then obtained. We may proceed in this manner for all points along the equipotential line as far as is desirable.

Projecting lines back to the *Potential*-axis from the points B, D, etc., increments dV are cut off which give the difference of potential between the base line and the approximate equipotential line for every point considered. If the increments dV

* Communicated by Prof. Jakob Kunz.

are equal, then the drawn curve is truly an equipotential line and the drawing is correct.

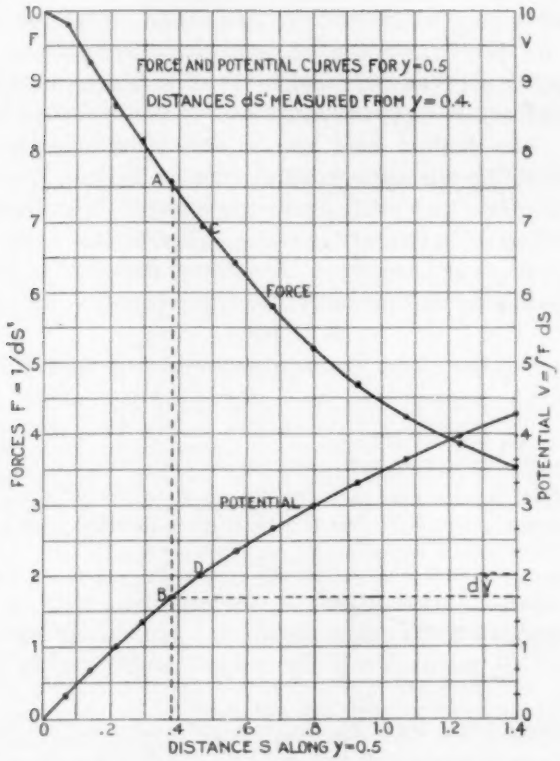
The whole field may be checked in this manner and corrected to exactness. This method, when properly used, will give the true conformation of the electric field which will, in fact, be the solution of Laplace's equation for the particular case in hand.

$$\Delta V = 0$$

EXAMPLE.

The field has been constructed and checked for the case of a thin wire strung through the centre of a circular hole in a thin

FIG. 1.



infinite plane. The field is shown in two dimensions in Fig. 2, the iV-axis representing the central wire and the U-axis from $\pm$ 1 to ∞ representing the thin plate. The field is symmetrical and may be represented in three-dimensional space by rotating the diagram about the iV-axis.

This field is in reality an orthogonal system of confocal ellipses and hyperbolas and may be represented by the equation,

$$w = \cos h\ z = U + iV$$

where z is the complex number,

$$z = x + iy$$

This equation is easily solved for the functions U and V,

$$W = \cos h\,(x + iy)$$

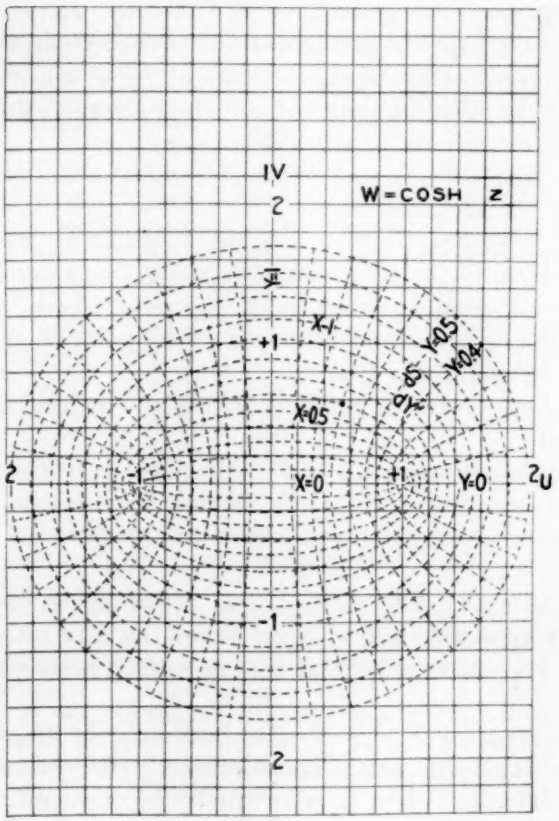
$$W = \frac{e^z + e^{-z}}{2} = \frac{e^{(x+iy)} + e^{-(x+iy)}}{2}$$

$$W = 1/2\ e^x(\cos y + i \sin y) + 1/2e^{-x}(\cos y - i \sin y)$$

$$W = \cos y \frac{e^x + e^{-x}}{2} + i \sin y \frac{e^x - e^{-x}}{2}$$

$$W = \cos y \cos h\, x + i \sin y \sin h\, x = U + iV.$$

FIG. 2.



Which gives

$$U = \cos y \cos h\, x.$$
$$V = \sin y \sin h\, x.$$

and

Squaring the equations and subtracting gives

$$U^2/\cos^2 y - V^2/\sin^2 y = 1,$$

which is the equation for a family of confocal hyperbolas. Giving different values to y, we find the family of hyperbolas having their foci at ± 1.

Adding the squared equations gives

$$U^2/\cos^2 h\, x + V^2/\sin^2 h\, x = 1,$$

the equation for a family of confocal ellipses with foci at ± 1, the same foci as for the hyperbolas.

To illustrate the method, we will take the equipotential line $y = 0.4$ as the base line and measure the distances ds' to the equipotential line $y = 0.5$, along the lines of force which are represented by the different values of x. These distances are recorded in the second column of the table.

Assuming $dV = 1$, the forces $F = 1/ds'$ are found and recorded in the third column.

Now, beginning from $x = 0$, the ds distances between consecutive lines of force are measured along $y = 0.5$ and recorded as in column four.

Column five gives the distance s to any point on $y = 0.5$ from the starting point on $x = 0$.

The forces for each point on the line $y = 0.5$ are now plotted as in Fig. 1.

Integrations under the *Force*-curve are performed and the results recorded as in the sixth column, from which values the *Potential*-curve is plotted and projections made to the *Potential*-axis.

The potential differences dV as found along each line of force are approximately of equal values, as may be seen in the last column, which means that the line $y = 0.5$ is an equipotential line.

In this manner it is possible to check over the entire field and to change the rough approximate drawing to the correct form.

The drawing in Fig. 2, representable by $w = \cosh z$, is a true

electric field where the lines represented by the y values are the equipotential lines and the lines represented by the values of x are the lines of force.

SUMMARY.

1. A graphical method is explained which permits the construction of any electric field, or the solution of Laplace's differential equation.

2. As an example the field for a thin wire strung through a circular hole in an infinite plane is given.

3. This field is representable by $w = \cosh z$.

In conclusion, I wish to thank Dr. J. Kunz for a suggestion regarding the given graphical solution of Laplace's differential equation.

TABLE.

Potential Difference Between $y = 0.4$ and $y = 0.5$.

ON x	ds'	$F = 1/ds'$	ds	S	$\int_0^S F\,ds = V$	dV
0.0	0.100	10.000	0.000	0.000	0.00	0.00
0.1	0.102	9.800	0.068	0.068	0.33	0.33
0.2	0.108	9.250	0.092	0.140	0.67	0.34
0.3	0.116	8.625	0.076	0.216	1.01	0.34
0.4	0.120	8.320	0.078	0.294	1.34	0.33
0.5	0.132	7.575	0.084	0.378	1.68	0.34
0.6	0.144	6.950	0.092	0.470	2.02	0.34
0.7	0.156	6.410	0.100	0.570	2.34	0.32
0.8	0.172	5.810	0.110	0.680	2.66	0.32
0.9	0.192	5.210	0.118	0.798	2.99	0.33
1.0	0.212	4.715	0.130	0.928	3.31	0.32
1.1	0.236	4.240	0.142	1.070	3.64	0.33
1.2	0.260	3.850	0.160	1.230	3.96	0.32
1.3	0.284	3.525	0.172	1.402	4.28	0.32

UNIVERSITY OF ILLINOIS,
June, 1917.

The Use of Windmills in Irrigation in the Semi-arid West. P. E. FULLER. (*U. S. Department of Agriculture,* Farmers' Bulletin 856.)—The feasibility of windmill irrigation depends much upon the head or height of water that must be lifted from the well, and it is scarcely practicable to use windmills for irrigation purposes if the water table or level is over 60 feet from the surface of the ground. Raising small quantities of water against a high head by such power is practicable for stock or domestic use, but the

limited power of the ordinary mill is not sufficient to pump the large volumes needed for irrigation. As there is only a small percentage of time during which the wind attains a velocity favorable to the most economical mill load, the total quantity of water will be small unless a very large mill is used. Many mill manufacturers stipulate that their mills will perform certain work in an average velocity of 16 miles per hour during eight hours per day, but this is misleading and may result in an overestimate of the results expected. The average hourly velocity should not enter into the choice of a mill; the basis should be the time during which the wind maintains certain rates per hour.

It might be supposed, naturally, that if the load is too small for the mill, the small amount of water pumped per stroke would be compensated by the greater number of strokes made by the mill. While this is true to some extent, it should be remembered that there is but one economical or efficient speed for each wind velocity. If the load cannot be varied with each change of wind velocity, the best economy will be obtained by adopting a cylinder which will load the mill at the most economical point during the greatest time possible. Several devices have been invented for adjusting the load to the wind velocity. Some are operated by hand, but this mode of operation is impracticable. One regulator lengthens the stroke of the pump automatically as the wind increases in velocity and shortens the length of the stroke as the wind velocity decreases. The average gain in water pumped through the application of the stroke regulator was found in a test to be approximately 30 per cent. This regulator has demonstrated its applicability to windmill work, and if by certain changes in mechanical construction its durability can be assured, it will prove a valuable device in windmill operation.

The practice of some manufacturers of decreasing first cost by the use of inferior metal of inadequate section in windmill towers is to be regretted. A tower should have sufficient strength to safely withstand the highest wind velocities, and the slight additional cost entailed is amply justified. Wooden towers are good where clear timber is available at a reasonable cost, but unless they are substantially built and kept painted their life is short. In some localities, however, wooden towers have made an excellent record for long life. In the vicinity of Stockton, Calif., some old wooden mills have been in service 30 years. The height of the tower has much to do with the success of a mill. It should never be located where the wind is obstructed in its free access to the mill, and it should be high enough above the ground to realize the full effect of the wind. Ordinarily 40 feet will give excellent results, though in some places the wheel may be set only a few feet above the ground. If more than one mill is used, the location with respect to each other should be given consideration, for if placed in line with the prevailing wind one will obstruct the wind considerably, even if placed at such distances apart as 500 feet.

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

GAS-MANTLE LIGHTING CONDITIONS IN TEN LARGE CITIES IN THE UNITED STATES.[1]

[ABSTRACT.]

FROM a careful inspection of about 4500 gas-mantle lamps in service in ten cities a summary of the condition of mantles, glassware, pilot light, and other particulars was made in order to determine to what extent the customer benefited through periodic maintenance service. By those observations it is found that a lamp not on regular maintenance is likely to be defective five and a half times as frequently as a lamp which is regularly maintained. Also, it is shown that, on the average, one in three of the lamps on regular maintenance was not in good condition, whereas the defects noted in the lamps not so maintained average more than one for every lamp.

THE DETERMINATION OF ABSOLUTE VISCOSITY BY SHORT-TUBE VISCOSIMETERS.[2]

[ABSTRACT.]

THE Engler and the Saybolt Universal viscosimeters, which are the instruments usually employed in the oil trade, have such short outlet tubes that the equation for the flow through long capillary tubes is not applicable without correction factors. The literature has been carefully reviewed and further experimental work has been done. The conclusion is reached that water is not a suitable liquid for use in finding the relation between viscosity and time of discharge for short-tube viscosimeters, and that Ubbelohde's equation, and all others based upon it, are seriously in error.

EFFECTS OF HEAT ON CELLULOID AND SIMILAR MATERIALS.[3]

[ABSTRACT.]

A STUDY of the behavior of celluloid and of pyroxylin plastics in general, when heated to different temperatures, com-

* Communicated by the Director.

[1] Technologic Paper No. 99.

[2] Technologic Paper No. 100.

[3] Technologic Paper No. 98.

mences in the neighborhood of 100° C., and above this temperature the heat of decomposition may raise the temperature of the mass to the ignition point. At 170° C. decomposition takes place with explosive violence. Pyroxylin plastics can be ignited by momentary contact with bodies having a temperature of 430° C. and upward. The rate of combustion is five to ten times that of poplar, pine or paper under the same conditions. The vapors evolved during the decomposition of pyroxylin are poisonous and extremely combustible, and may be ignited by the heat of decomposition.

PUBLIC UTILITY SERVICE STANDARDS OF QUALITY AND SAFETY.[4]

[ABSTRACT.]

A BRIEF outline of the public service activities of the Bureau, together with lists of the publications bearing on the various subjects which are issued by the Bureau. The subheadings giving the public service activities are: Standards for Electric Service, Standards for Gas Service, Standard Methods of Gas Testing, National Electric Safety Code, Electrolysis Mitigation, Further Activities.

ANNUAL REPORT OF DIRECTOR.

SCIENTIFIC work of unusual volume and interest is described in the annual report of the Director of the Bureau of Standards, just issued. The work ranges from the testing of clinical thermometers to the publication of national electrical and gas codes. Since the war began, all branches of this scientific bureau have been conducting researches on technical problems of military application. The regular work, however, has not been overlooked. In fact, the variety and importance of the results obtained during the year in its scientific and technical researches are of unusual interest.

The standardiaztion work has comprised the making of 155,000 tests of weights, measures, measuring instruments, and materials; the promulgation of a new standard screen scale for unifying the sizes of industrial sieves; the new gauge standards laboratory for testing munitions gauges; investigation of the

[4] Circular No. 68.

accuracy of leather measuring instruments; standardizing blood-counting apparatus, including new specifications based on researches on the errors of such apparatus; the standardization of master scales in 21 states and of the master scales of the American Railway Association; extension of the work on altitude measuring instruments to include all varieties of aviation instruments; and a large number of special researches in physics of materials.

The report describes much interesting work on standards for electrical measurements; radio researches; practical tests of the Bureau's radio fog-signalling system; radio direction finder; magnetic system of testing steels to ascertain quality for tool making, rail making, ball bearings, and the like; standardization of radium and radio-active preparations, including radium luminous paints for watch dials, and the dials of aviation instruments; inauguration of the work on X-ray standardization; improved methods of light measurement; standard practice codes issued as national standards for electric service and for gas service; work on standards for street lighting service, and on standards for telephone service; investigation of gas-mantle conditions in the leading cities; and the important work of safeguarding underground structures from the damage caused by stray electric currents.

The optical work of the Bureau is of special interest and includes the precise measurement of wave-lengths of various colors for use as standards in optical work, red and infra-red photography as applied to the photography of the spectra of laboratory materials, and of the stars and the sun; optical methods of finding impurities in materials; sugar determination by optical means; determination of sugar content of molasses; industrial standards of color for certain industrial materials; standardization of optical apparatus, such as camera lenses, field-glasses, range finders, and similar equipment; analysis of radiation with respect to energy distribution.

The chemical work of the Bureau included the development of new methods of analyzing steel and other materials; study of platinum purity; coöperation upon military researches involving chemistry, such as the preparation of special gases, combustion gas detectors; and chemical researches and materials testing in great variety and quantity for the Government.

The Bureau's technologic work comprises a wide range of researches into the special technologies of the metals, cement, clay, clay products, lime, stucco, paints, roofing materials, and miscellaneous materials, such as paper, textiles, rubber, leather, glass, and the like. The results are published by the Bureau in a series of about 20 technologic papers issued during the year.

The regular growth of the Bureau and its special expansion on account of war work have resulted in the construction of several new laboratories and an increase in the staff of about sixty per cent.

To all interested in the applications of science to industry and to warfare the annual report of the Bureau of Standards will be of particular interest.

Waterwheel Reversed to Absorb Energy During Test. ANON. (*Engineering News-Record*, vol. 79, No. 22, p. 1023, November, 1917.)—The contract for the hydraulic equipment in the crosscut hydroelectric plant built for the U. S. Reclamation Service on the Salt River Reclamation Project in Arizona was let with a bonus or penalty dependent upon the efficiency obtained. A study and comparison of methods of conducting the test revealed the inadvisability of using the usual water rheostat methods of absorbing the load. With the consent of the waterwheel manufacturer it was therefore decided to connect the generator of the wheels under test with the generator of another unit in such a way that the latter could be run as a motor. Thus the load could be taken up by the jets from the nozzles, retarding the reverse rotation of the buckets.

The specifications provided that any one of the six units might be selected for the test. On bringing the machine selected for test to speed, the machine selected for load also came up to speed as a synchronous motor. The connections on the unit intended to supply the load were reversed, of course, so that when supplied with power from an external source its direction of rotation was opposite to normal. After some experiment it was decided to disconnect the governors and rely entirely on hand regulation. One penstock was used for supplying water to the unit under test and another for supplying water to the exciters and providing the load in the braking unit. With water through the nozzles of the unit operated as a synchronous motor, electric energy was absorbed in direct relation to the hydraulic energy developed by water passing through its nozzles. Therefore, as the nozzles were gradually opened on the unit under test, a relative additional quantity of water was admitted to the motor unit.

NOTES FROM THE RESEARCH LABORATORY, EASTMAN KODAK COMPANY.*

HIGH-TEMPERATURE DEVELOPMENT OF ROLL FILM, FILM PACKS, PLATES, AND PAPER.[1]

By J. I. Crabtree.

[ABSTRACT.]

ROLL film, film packs, and plates, whether new or date-expired, may be successfully developed under tropical conditions (up to 95° F.) by means of most developers, with the addition of 10 per cent. sodium sulphate and some potassium bromide in order to prevent fog, but much better with a special developer compounded with paraminophenol hydrochloride. Although it has been recommended to develop film in the tropics by hardening the same, either before or after development, by the addition of a hardener such as formalin, it is only possible to secure the best results by using a developer free from such addition agents. The formula for the developer is as follows:

Paraminophenol hydrochloride	7 grammes
Sodium sulphite (E. K. Co.)	50 grammes
Sodium carbonate (E. K. Co.)	50 grammes
Water to	1 litre

Rinse for only one or two seconds before placing in the fixing bath, otherwise the film is apt to soften in the rinse water.

The time of development with Eastman N. C. film at 95° F. for normal contrast is one and a half minutes, though the time of development may be doubled by the addition of 100 grammes of sodium sulphate (crystal) per litre of developer.

At temperatures up to 75° F. the regular acid fixing bath should be used, but at temperatures up to 85° F. the following chrome alum bath is necessary:

	Avoirdupois	Metric
Hypo	7 oz.	200 grammes
Sodium sulphite (E. K. Co.)	1 oz., 175 grains	40 grammes
Potassium chrome alum	2 oz., 350 grains	80 grammes
Acetic acid (glacial)	40 minims	2.5 c.c.
Water to	32 oz.	1 litre

* Communicated by the Director.

[1] Communication No. 62 from the Research Laboratory of the Eastman Kodak Company, published in *British Journal of Photography*, 1917, p. 551.

Dissolve the sulphite and chrome alum together and add to the hypo solution, finally adding acetic acid.

At temperatures up to 95° F. the following formalin bath should be employed:

	Avoirdupois	Metric
Hypo	9 oz.	250 grammes
Sodium sulphite (E. K. Co.)	1 oz., 350 grains	50 grammes
Formalin (formaldehyde 40 per cent.)	4¼ oz.	125 c.c.
Water to	32 oz.	1 litre

First dissolve the hypo, then the sulphite, and finally add the formalin.

In order to eliminate the odor of the formalin, the bath should be enclosed in a covered tank if possible. The above baths keep well at the temperatures stated, so that for the professional and amateur finishing trade the special chrome alum bath is very suitable, while in special cases, such as expeditionary work, when very high temperatures may prevail, the formalin bath will give perfect results.

Film packs may be successfully treated in a tray in the same way as N. C. film, though so far it has not been possible to devise a method for using the Kodak film or film pack tanks at the temperatures named.

Although no difficulty is to be expected when developing gaslight and bromide papers at high temperatures, the use of a stop bath of 3 per cent. acetic acid and twice the usual amount of liquid hardener in the fixing bath is recommended.

NOTES FROM THE RESEARCH DIVISION, ELECTRICAL ENGINEERING DEPARTMENT, MASSACHUSETTS INSTITUTE OF TECHNOLOGY.*

APPARENT DIELECTRIC STRENGTH OF VARNISHED CAMBRIC.

In December, 1913, a paper by Mr. F. M. Farmer was read before the American Institute of Electrical Engineers in New York on "The Dielectric Strength of Thin Insulating Materials." A large number of experimental observations were recorded in the paper, on the apparent dielectric strength of thin sheets of varnished cambric, hard rubber, oil, and air, when tested between opposed parallel circular disk electrodes of various diameters. It was shown that in all cases the apparent dielectric strength diminished when the diameter of the disk electrodes was increased. With varnished cambric sheets the dielectric strength diminished 13.4 per cent. between 1.1 and 5.1 cm. of disk diameter.

It is generally accepted that, provided the tested dielectric sheet has a thickness not exceeding, say, five per cent. of the disk diameter, the electric field across the sheet is very nearly uniform. It might therefore be supposed that the area of the tested sheet would not affect the breakdown voltage, which, in a strictly uniform field, should be simply proportional to the thickness of the test sheet and independent of the area.

The only reason that was suggested in the discussion following the paper for the apparent diminution in breakdown voltage with area was a "weak-spot" theory. That is, it was supposed that a large disk would probably cover more accidental weak spots than a small disk, and so would be likely to invoke a lesser breakdown voltage. It is impossible to deny the validity of this argument, and yet it is not easy to assign a quantitative value to this diminution according to such a theory. Moreover, essentially the same phenomenon was presented with films of oil and air, fluid media in which weak spots are not supposed to occur.

The subject received attention in the M. I. T. laboratories during 1913–1914 in thesis work. Mr. L. H. Webber repeated and confirmed a number of the original observations in the Farmer paper. Again, in 1914–1915, Mr. G. Y. Fong repeated

* Communicated by the Director.

the tests, with sheet cambric previously immersed in oil. The diminution in rupturing voltage with disk diameter was then found to be distinctly less with oil-immersed cambric than with air-immersed cambric.

A complete series of dielectric strength tests was then carried on in the years 1915–1917 by Dr. R. J. Wiseman, under an appropriation from the American Telephone and Telegraph Company. A great variety of mechanical and electrical conditions were tried. The simplest arrangement arrived at was to support a test sheet of varnished cambric upon a fixed flat horizontal metallic disk electrode 10 cm. in diameter. The upper electrode was then laid on top of the test sheet so as to lie symmetrically over the lower fixed electrode. The breakdown voltage was supplied from a sine-wave alternator, through a 10-kva. step-up transformer. The voltage on the primary or low-tension side of the transformer was regulated, by varying the field excitation of the alternator, in such a manner that the secondary electromotive force impressed on the test sheet rose at the rate of approximately 1000 r.m.s. volts per second. The electrodes of the test sheet were connected directly to the secondary terminals of the transformer by relatively short copper wires. Intermediate water resistances were used, at first, in these tests; but they were afterward removed without appreciable effect. A specially calibrated voltmeter in a tertiary circuit of the transformer enabled the r.m.s. electromotive force applied to the test sheet to be noted at the moment when rupture occurred.

It was found that when the upper electrode was a single metallic disk, the r.m.s. breakdown voltage fell off 13.3 per cent., as the area of the upper disk was increased from 1.1 to 18 sq. cm.

When, however, the upper electrode was formed of a number of separate brass disks, each 1.13 sq. cm. area, all resting on the test sheet and each connected to a common terminal by a straight, fine copper wire 40 cm. long, there was only about 1 per cent. diminution in breakdown voltage when the number of the little upper disks was increased from 1 to 16, with a corresponding increase in total active area from 1.1 to 18.1 sq. cm.

It thus became evident that the diminution in apparent dielectric strength with increase in size of the disk electrodes did not depend upon the active electrode surface, but upon the way in which the electrode surface was put together. This test was

checked with different observers and apparatus at the Electrical Testing Laboratories in New York.

It was further ascertained that when the multiple upper electrode disks were set together into a connecting brass backing or frame the diminution in breakdown voltage with increase of active area from 1.1 to 18.1 sq. cm. increased to about 15.4 per cent., or even more than with the original single brass disks.

Again, when the multiple upper electrode disks were set into a hard-rubber back frame and connected together by short, strong copper wires immediately above the rubber frame, the diminution of voltage was 10.8 per cent.; whereas, if the connection was made by fine, straight copper wires about 40 cm. long to a common terminal, the diminution fell to 5.8 per cent.

By the courtesy of Mr. Farmer, all of these tests were repeated at the New York laboratories and checked in substance, although the agreement as to diminution was not precise in detail.

No satisfactory demonstration has yet been obtained as to the reasons for the above-mentioned phenomena. They suggest, however, the possibility of the existence of very high-frequency electric oscillations superposed upon the voltage wave of the testing frequency, which was 60 cycles per second throughout. It is conceivable that when a high-potential alternating electromotive force is impressed upon the two disk electrodes, which form, with the interposed test sheet, a condenser, high-frequency disturbances may be set up between different parts of the condenser, considered as an oscillating system. If such high-frequency oscillations occurred, air pocketed between the surface of the varnished cambric and either electrode would be ionized, and the ions might actively bombard the dielectric in the destructive manner which Ryan and other high-frequency experimentalists have already demonstrated. When the disk electrodes are enlarged, the frequency of such parasitic free oscillations would be lowered, but their amplitude and energy would be increased. If, however, the electrode surface is broken up into elements connected together by relatively long, thin wires, such oscillations would be damped and hindered. Confirmatory experimental evidence will, of course, be necessary before such a theory of diminution in breakdown voltage with disk diameter can be reliable.

A more detailed description of the tests and apparatus appears in *Electrical World* for December 15, 1917, vol. 70, No. 24.

The Technic of Reading. L. LAURANCE, in *Institute Journal* (London). (*The Optical Journal and Review*, vol. 40, No. 24, p. 1530, December 6, 1917.)—When a person is reading, all that he can see clearly at any given moment is that amount of type whose image can be included in the true macula area. About 25 mm. is the length of print which can be read without movement of the eyes. Actually it is not so much; the angle of clear vision includes, at the usual reading distance, some one and a half words or perhaps two short ones. The eyes are converged for the reading distance as if the point of fixation were always on the median line, and the convergence is maintained as the eyes rotate right and left in order to read each word in each line of print, although at given moments the print is immediately opposite to one and the other eye.

The rotations of the eyes from left to right are not achieved by a continuously gliding movement, but by jerks and pauses. When the two eyes are turned to the left to fix the beginning of a line, the fixation point will be automatically a little to the right of the first letter; the first word or two having been read, the eyes are jerked over to the next external macular field, there being then a pause in order that it may be seen and mentally appreciated, and so successively until the whole line is read. The jerks are exceedingly rapid, but the pauses occupy a definite length of time, sufficiently great for the retinal image to be formed and communicated to the brain. The number of jerks and pauses varies with the length of the line, the number being, say, 5 to 8. The difficulty met with when reading very long words consists partly in the fact that more than a single pause is required to cover them visually.

The educated individual reads more rapidly than the uneducated because he does not need so many pauses to a line; he takes longer jerks and mentally fills in any letters or short words that he does not see clearly. The person of lower mentality must visualize every word, and indeed every letter, in order to grasp the meaning of what he reads. In fact, this occurs with educated persons also when reading matter with which they are unaccustomed. This natural failure to visualize every letter accounts for the fact that a misprint can be unnoticed by innumerable readers of a book or paper.

As a rule, there is not a great deal of vertical rotation in order to see letters, but, again, there is a marked difference between the trained and the untrained reader. The former views mainly the upper parts of the letters and mentally fills in the lower; the latter must see the whole of each letter and expend time in vertical eye movements in order to do this. It is a well-known fact that it is comparatively easy to read type of which the lower halves are covered, whereas it is very difficult to do so if the upper halves are hidden from view and the lower only exposed.

THE FRANKLIN INSTITUTE.

(Proceedings of the Stated Meeting held Wednesday, December 19, 1917.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 19, 1917.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 2.

Mr. Louis E. Levy, chairman *pro tem.* of the Committee on Science and the Arts, reported the condition of the work of the committee.

The following nominations were made for officers and managers to be voted for at the annual election to be held on January 16, 1918:

For President (to serve one year), Walton Clark.

For Vice-President (to serve three years), Louis E. Levy.

For Treasurer (to serve one year), Cyrus Borgner.

For Managers (to serve three years), Charles Day, Kern Dodge, Alfred W. Gibbs, George R. Henderson, George A. Hoadley, Isaac Norris, Jr., Lawrence T. Paul, James S. Rogers; (to serve two years) Gellert Alleman.

Mr. Louis E. Levy, on behalf of the Committee on Science and the Arts, then introduced Mr. Edward C. Baker, president of the International Money Machine Company, and representative of Mr. Thomas Bilyeu, who had been recommended for the award of the John Scott Legacy Medal and Premium for his inventions embodied in the International Money Machine. The President presented the medal and accompanying certificate to Mr. Baker, who thanked the Institute on behalf of Mr. Bilyeu for this recognition.

The paper of the evening, on "Military Highways," by Logan Waller Page, Director of the Office of Public Roads and Rural Engineering, U. S. Department of Agriculture, was presented by Mr. E. W. James, general inspector of the office. The location, control, and design of modern highways were given consideration, as well as the use and maintenance of these in the light of the great development of motor transport. The lessons taught by the military and economic development incident to the movement and supply of great bodies of troops on European battlefields were pointed out. Consideration was also given to the defensive value of highways properly correlated with the schemes of civil development now in operation among the several states.

After a brief discussion the thanks of the meeting were extended to the speaker.

Adjourned.

GEORGE A. HOADLEY,
Acting Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(Abstract of Proceedings of the Stated Meeting held Wednesday, December 5, 1917.)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 5, 1917.

MR. CHARLES E. BONINE, *Chairman pro tem.*

The following report was presented for first reading:

No. 2703.—Sweetland Filter Cloth.

The following reports were presented for final action:

No. 2693.—Dressler Tunnel Kiln. Conrad d'Huc Dressler, of Great Marlow, England, recommended to the City of Philadelphia for the John Scott Legacy Medal and Premium.

No. 2705.—Levy Hæmocytometer. Recommended that the Edward Longstreth Medal of Merit be awarded to Max Levy, of Philadelphia, Pa.

GEORGE A. HOADLEY,
Acting Secretary.

SECTIONS.

Section of Physics and Chemistry.—A meeting of the Section was held in the Hall of the Institute on Thursday evening, December 6, 1917, at 8 o'clock, with Dr. George A. Hoadley in the chair. The minutes of the previous meeting were approved as read.

Henry Norris Russell, Ph.D., Professor of Astronomy in Princeton University, and director of its Observatory, delivered an illustrated lecture on "The Use of Photometric Methods in Astrophysics." The photometric methods used in astrophysical research were enumerated, and a description was given of the results obtained by the application of these methods in the study of the sun, moon, asteroids, planets, satellites, rings of Saturn, variable stars, eclipsing variables, nebulæ, star clusters, and the Milky Way.

The paper was discussed by Prof. Eric Doolittle and others. On motion of Dr. Herbert E. Ives, a vote of thanks was extended to Doctor Russell. The meeting then adjourned.

JOSEPH S. HEPBURN,
Secretary.

Mechanical and Engineering Section.—A joint meeting of the Section and the American Society of Mechanical Engineers was held in the Hall of the Institute on Tuesday evening, December 11, 1917, at 8 o'clock.

Dr. George A. Hoadley, acting secretary of the Institute, and Mr. L. F. Moody, chairman of the Philadelphia Section, American Society of Mechanical Engineers, presided jointly. Mr. Joseph A. Steinmetz, of Philadelphia, presented the paper of the evening, entitled "Offensive Against the Submarine."

The speaker described the various methods and devices in use for combatting the submarine, and gave consideration to many of the suggestions which have been made for defeating the operation of this naval menace. A historical *résumé* of the subject was also presented. A large number of lantern slides were shown.

After a brief discussion the thanks of the meeting were extended to Mr. Steinmetz.

Adjourned.

ALFRED RIGLING,
Acting Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, December 12, 1917.)

LIFE.

MR. HENRY WOODHOUSE, Editor, *Aerial Age* and *Flying*, Foster Building, Madison Avenue and Fortieth Street, New York City, N. Y.

ASSOCIATE.

MR. LEON C. BIBBER, Marine Engineer, P. O. Box 64, Portland, Maine.

CHANGES OF ADDRESS.

MAJOR GEORGE S. CRAMPTON, Director of Field Hospitals, Camp Hancock, Augusta, Ga.

LIEUT. J. G. DETWILER, 1237 Seltzer Street, Philadelphia, Pa.

MR. PENROSE R. HOOPES, 1015 South Farragut Terrace, Philadelphia, Pa.

LIEUT. CHESTER LICHTENBERG, General Engineer Depot, U. S. Army, 1438 U Street, N. W., Washington, D. C.

LIEUT. THOMAS S. MARTIN, 3D, 1913 I Street, N. W., Washington, D. C.

DR. G. H. MEEKER, The School of Medicine, University of Pennsylvania, Philadelphia, Pa.

MR. FRED J. MILLER, Box 27, Center Bridge, Pa.

MR. CHARLES PENROSE, care of Day & Zimmerman, 611 Chestnut Street, Philadelphia, Pa.

MR. OSCAR L. SCHEHL, 1631 Girard Avenue, Philadelphia, Pa.

MR. A. F. SHATTUCK, 615 Canon Drive, Beverly Hills, Calif.

MR. L. H. THULLEN, General Delivery, Greenport, N. Y.

LIBRARY NOTES.

PURCHASES.

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JACKSON, D. C., and MCGRATH, D. J.—Street Railway Fares: Their Relation to Length of Haul and Cost of Service. 1917.

LAWS, F. A.—Electrical Measurements. 1917.

MEYERS, G. J.—Steam Turbines; A Treatise Covering U. S. Naval Practice. 1917.

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Griscom-Russell Company, Bulletins Nos. 224, 225, and 1108. New York, no dates. (From the Company.)

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Technical Photography and its Use in Industrial and Commercial Organizations. J. H. GRAFF. (*The Journal of Industrial and Engineering Chemistry*, vol. 9, No. 11, p. 1053, November, 1917.)—Practically no active technical, industrial, or commercial organization is complete without a photographic equipment in one form or another. With the exception of very few large establishments that maintain a photographic department for the purpose of photographing salesmen's samples, etc., there was until recently no concern in which a photographic department was installed as a distinct unit of the business, whose function it is to serve all the other departments and the company as a whole. The author believes himself to be one of the first to establish such a department in a large corporation, and to-day that photographic department has become a necessity.

In a large project of this kind the manager should be not only a photographer in the fullest sense of the word, but should also have a technical education and an adequate knowledge of the business to be served. Besides an equipment for copying documents of various kinds and laboratory and field photography, there are many advantages in facilities for the production of color work and photomicrography in the commercial field. The cost of a complete equipment is considerable, but this can be installed and developed by degrees in cases where the magnitude of the business served does not warrant a large expenditure. Perhaps one of the greatest difficulties of conducting a project of this kind is that of securing a duly qualified manager, and the author hopes to see established some day the profession of "Photographical Engineer," embracing the necessary theoretical and practical training for the purpose.

CURRENT TOPICS.

Stellite as a Substitute for Platinum. E. HAYNES. (*Proceedings American Chemical Society,* September 10 to 13, through *The Journal of Industrial and Engineering Chemistry,* vol. 9, No. 10, p. 974, October, 1917.)—Owing to the great scarcity of platinum and its consequent high price, platinum substitutes have been eagerly sought, particularly within the last three or four years. From what has already been accomplished in this direction it is evident that no single metal or combination of metals will fully take the place of platinum. The alloy of gold with palladium affords a partial substitute for crucibles and dishes, and perhaps more nearly replaces platinum in this respect than anything yet offered. The price of this alloy, however, is comparatively high, though, bulk for bulk, it is only about half as costly as platinum. The alloy of nickel with chromium, the silicon-iron alloys, and pure quartz have also given satisfactory results for certain laboratory purposes.

The stellite alloys are not fixed or definite in their composition, but may be divided broadly into two classes: (1) those malleable at red heat, and (2) those that can be worked into the desired form only by casting. The malleable alloys are composed almost entirely of cobalt and chromium, and the proportion may vary from 10 to 50 per cent. of chromium, with a corresponding variation of the other constituent. These alloys are very hard and resist nitric acid almost perfectly, even when boiling, particularly if the chromium content is over 15 per cent. They forge with difficulty at temperatures varying from 750° to 1200°. They have been forged into table implements, cutlery, chemical apparatus, and jewelry.

The malleable alloys are all slowly attacked by either hydrochloric, sulfuric, or hydrofluoric acid, but are nearly immune to all chemical combinations, as well as to the fruit acids. As evaporating dishes made of this metal take a bright polish, and can be made of comparatively light section, they will prove suitable for evaporating many chemical salts to dryness, and particularly suitable for boiling the caustic alkalies. Substances may be evaporated to complete dryness in these vessels without danger of breakage, since the tensile strength of the alloy exceeds 100,000 pounds per square inch. The vessels retain their lustre under practically all chemical laboratory conditions. The alloy also gives most excellent results in the form of lamp stands, supporting rings, triangles, etc. They can be heated to full redness without the formation of scale, and subjected to temperatures up to 1200° C., and still retain considerable strength. In fact, the stellite alloys possess the highest "red hardness" of any of the alloys yet discovered.

In many cases stellite may be substituted to great advantage for

platinum in jewelry. It is almost of the same color, possesses a higher lustre, and retains its lustre very much better than platinum, since it is so hard that it is not scratched or abraded by ordinary use. While not nearly so pliable as platinum, it can be worked into many forms in jewelry without special difficulty.

Iron-wire Transmissions for Rural Extensions. L. P. PERRY. (*Electric World,* vol. 70, No. 15, p. 713, October 13, 1917.)—Many sparsely settled communities are deprived of electric service because central station companies cannot afford to build the lines to serve them. In fact, from data which have been collected, some rural copper-wire lines built to the standard used in well-settled districts have been unprofitable to the operating companies because the revenue obtained did not even pay for the overhead charges on the investment. In such cases, or where service is required for only a short period of years and the wire must be subsequently taken down, companies have had to look for cheaper methods of construction. Iron-wire transmission has been tried extensively of late, the companies taking advantage of the lower cost of conductors and the higher tensile strength, which permits larger pole spacings and consequently smaller investment in poles and insulators.

Seeing the possibilities in the use of iron wire, but being confronted with a state law which compelled it to secure the approval of the State Public Service Commission before such construction could be adopted, the Central Connecticut Power and Light Company has taken up the subject with the commission and received permission to use iron wire for certain extensions. At the time the request was made several 2200-volt line extensions had been promised to customers along a 13,200-volt transmission line, it being the intention to put cross-arms on the existing pole lines to accommodate the proposed 2200-volt circuit. This construction has not yet been approved, however, presumably because it has not yet been ascertained whether the high-voltage wires might break and come in contact with the low-voltage wires beneath.

At the conferences which were held the commission was alarmed lest the proposed types of construction should be more dangerous to the public than the present standard. In support of the petition it was shown that No. 6 bare double-galvanized B. B. iron wire is about one size larger and very much stronger than the commonly used No. 6 B. & S. gauge weather-proof copper wire. Iron wire has the further advantage of not having to carry a load of weatherproof insulation. Weatherproof copper wire is usually soft or medium drawn and much weaker than hard-drawn copper or iron wire.

If weatherproof copper wire is pulled up taut during hot weather it will contract and become so taut in cold weather that the wire draws out to a slightly smaller diameter. In the winter, when it is loaded heavily with sleet and subjected to high wind pressures, the tension may become so great that it will lengthen and sag until the

tension has been reduced. During the following summer, owing to the higher temperatures, the wires will sag still further. Iron wire supported on poles placed 250 feet apart to give 6-foot sags is much stronger and much more likely to retain its original length and position than copper wire, usually erected on more closely spaced poles.

In the opinion of the commission, there seemed to be no question as to the strength of galvanized-iron wire when first installed, but the liability to rusting was viewed with some alarm. The petitioner held that iron wire can rust considerably before its cross-section is reduced to the point where it would be seriously weakened. If a small iron telephone wire is safe for ten or twenty years, the larger wires proposed for transmission purposes will, of course, have a longer life, since the larger the diameter the less the relative surface exposed to rust compared with the weight. Furthermore, although practically all 600-volt trolley wires suspended over the heads of pedestrians in busy city streets are supported by stranded galvanized-iron wire, casualties due to the rusting away of these wires seldom occur. While the commission was apparently satisfied with the initial strength of the proposed iron wire, it demanded, in granting permission for its use, that the operating company use extra vigilance during the semi-annual line inspection.

Advisability of Higher Steam Pressures. J. T. FOSTER. (*Electric World*, vol. 70, No. 23, p. 1090, December 8, 1917.)—At the time the subject of higher steam pressures was first brought prominently before the engineering world in 1915 there seems to have been some doubt as to whether it would be practicable to attempt a gain in thermal efficiency by increasing pressures much above those now in use. Since that time, however, it appears that considerable thought has been given to the subject, and a number of prominent engineers have expressed the view that high pressures are not only feasible, but inevitable. Previous discussions have been confined to thermal efficiencies, but a consideration of water rates is of greater practical interest. Calculations from Goodenough's formulas, published in Bulletin 75 of the Engineering Experiment Station of the University of Illinois, show how thermal efficiencies and water rates vary at boiler temperatures of 500°, 600°, and 700° F. with a vacuum of 28½ inches at the exhaust. From these results the lowest water rate of 6.95 pounds was found to occur at a pressure of 1100 pounds absolute and at a temperature of 700° F.

Practical considerations seem to offer no insuperable difficulties. Engineers experienced in the design of boilers and turbines have expressed the view that, while a certain amount of re-design will be necessary, the changes in the case of 500-pound or 600-pound operating pressures are not radical, and that as soon as there is sufficient demand the work of developing high-pressure apparatus will be undertaken. No reasons appear why large gains should not be realized. The change from 200 pounds to 500 pounds and 600

pounds is no more revolutionary than the change which was made at the time standard practice raised the pressure from 80 pounds to 200 pounds or more. In view of the fact that the earlier change netted a gain of approximately 20 per cent., the expected gain in economy from the change to 500 pounds or 600 pounds does not seem excessive.

A New Method of Constructing Difficult Foundations. E. A. PRENTIS, JR. (*Engineering News-Record*, vol. 79, No. 23, p. 1061, December 6, 1917.)—During the construction of the subways in New York City, particularly in the skyscraper district of Manhattan, a great deal of underpinning has been done. From experience in carrying on this work, a new method of constructing foundations for new buildings has been developed. The method may be said to consist in underpinning the building during its erection, so that the construction of the foundation goes hand in hand with that of the building itself. It is evident that with such a method a great saving of time can be effected—where, for instance, caissons would be needed to carry the column loads and a spread foundation is out of the question.

In the new method the foundations are designed in the usual way as pile foundations. Steel shells for the piles are driven a small distance into the ground, from 5 to 10 feet, by means of a hammer, and are cleaned out and concreted. Wooden blocks 3 or 4 feet long are placed on top of the piles, and the space around the blocks and the tops of the piles is back-filled with carefully tamped earth. A reinforced concrete girder with the necessary grout pipes is then cast on the back-fill and posts, thus supplying a preliminary support for the column loads. The footing so constructed is ready for the beginning of the construction of the building. When the building has reached three or four stories—of perhaps twenty to be built—the second stage of the construction proceeds. The column by this time supports sufficient weight for jacking purposes. Each wooden post is then removed and the pile jacked until the desired reaction is obtained. The load is then transferred to two I-beam posts or their equivalent on each side of the jack, the jack removed, and the I-beams concreted in as well as space allows. Final contact is made by means of the grout pipes.

Wood Trusses Incased in Concrete. ANON. (*The Contract Record*, vol. 31, No. 48, p. 983, November 28, 1917.)—Casing timber roof trusses in cement to protect them against fire and acid fumes is a novel method employed recently in the buildings of a large oil refinery in Texas. Wood construction was adopted on account of the shortage of structural steel. After the trusses had been erected each member was wrapped with a single layer of light water-proof building paper, placed close against the surface and fastened with carpet tacks. The object of this covering is to prevent any bond be-

tween the concrete and the wood and to protect the latter from the moisture used in applying the concrete casing.

Sheets of expanded metal with ½-inch diamond mesh were then cut and shaped to fit the members and fastened by No. 12 nails and special chairs stamped from flat-steel strips. These chairs kept the expanded metal ⅝ inch from the surface, so that it would be embedded completely in the concrete. Guide strips were tacked along the edges of the members to obtain the proper thickness of casing and to act as striking boards for the corner lines. With the work thus prepared, a 1½-inch coating of cement mortar of "guncrete" was applied with cement guns. These operated under an air-pressure of 35 pounds, supplied by two oil-driven compressors, each having a capacity of 250 cubic feet per minute. Before this coating had fully set, the guide strips were removed and the surfaces left with an even finish.

The roof covering consists of a 1½-inch monolithic slab, built in place. Over the trusses and purlins was stretched a sheet of wire-mesh reinforcing secured by nails and chairs as noted above. Light wood panels were then laid upon this, and the concrete for the under side of the roof slab was shot in place by the cement gun. After about 24 hours the wood panels were removed. The concrete surface was then cleaned with compressed air and water to secure good bonding for the top coating, which was placed in the same way. Finally a thin coating of hot asphalt paint was applied. This work was done by the Cement-Gun Construction Company, of Chicago.

Liquid Oxygen as an Explosive. ANON. (*Mining and Scientific Press*, vol. 115, No. 20, p. 705, November 17, 1917.)—Utilization of liquid oxygen to form an explosive in connection with carbonaceous material has been revived by Mr. George S. Rice, of the Bureau of Mines. It is proposed to erect an experimental plant under Government auspices, in coöperation with the producers of the liquefied gas, who have shown great interest in the project. In a recent discussion before a meeting of the Mining and Metallurgical Society of America, Mr. Rice stated that shortage of materials commonly used in making explosives had led the Germans to adopt liquid air for saturating cartridges of carbonaceous matter to be employed for blasting coal in the mines of Upper Silesia. It was claimed that the efficiency of this makeshift explosive was equivalent to dynamite at 12 cents per pound.

Mr. Rice is using a mixture of various carbonaceous substances placed in a cheesecloth container along with a detonator; the cartridge is then dipped into liquid oxygen, and, although the best grade of oxygen at present obtainable is composed of only 55 per cent. of that element, a strength equal to about three-fourths of that 40 per cent. dynamite is realized. The function of the oxygen, of course, is to completely and instantaneously oxidize the carbon, the sud-

denness of the effect being such as to bring it within the realm of detonation. A large amount of information regarding explosives made with liquid oxygen is available, as this subject was extensively investigated about 18 years ago by a distinguished chemist, Sir James Dewar, in England. An experimental plant for its manufacture was also under consideration, if not actually erected, at Boston by a subsidiary of the British corporation. The investigations then made indicated favorable possibilities for the oxygen explosive, though some difficulties were experienced. Financial troubles prevented Dewar from continuing his efforts to commercialize the invention.

An Automatic Hydroelectric Plant. ANON. (*Electrical World*, vol. 70, No. 22, p. 1042, December 1, 1917.)—A hydroelectric generating station which is entirely automatic in all of its operations has recently been placed in service by the Iowa Railway and Light Company on the Cedar River, only a few blocks from the business district of Cedar Rapids. The plant, which will have an ultimate capacity of 2000 kilowatts, operates in parallel with an extensive transmission system which already reaches practically across the State of Iowa, except for a 28-mile break near Marshalltown. There are no instruments in the hydroelectric plant, these being installed in the company's steam station, which is about 0.6 mile distant. Three groups of conductors—power cables, instrument cables, and control cables—connect the two plants; hence, while the hydroelectric station is self-controlled and entirely automatic, it is possible for the steam-plant operators to supervise the action of the waterwheels and generators.

Perhaps the most spectacular and surprising feature of the whole plant is the speed with which the station goes into service. It requires just 37 seconds from the time the first switch operates until the first generator is under full load. A somewhat formidable array of mechanism might be expected in a plant of this nature, but the contactors and switches are inclosed in cabinets and the buses and control wires are run through bus chambers beneath the floor, so that the interior of the station appears very simple. With this arrangement, and by making each generator and its circuits, except for excitation, an independent unit, every element of the wiring and control apparatus has been made readily accessible.

The excitation for each machine is maintained at a fixed value at all times, thus simplifying the excitation problem, eliminating the necessity of voltage regulators, making it possible to take advantage of the full capacity of the river, and at the same time improving the power factor of the system through the operation of underloaded, overexcited machines. No oil governors are used for any of the machines, the gates being operated by motors which are upon complete automatical control at the hydroelectric station or remotely controlled from the steam station.

Repairing Marine Engine Castings by Electric Welding. E. P. JESSOP. (*Journal of the American Society of Naval Engineers*, vol. 29, No. 4, p. 639, November, 1917.)—Immediately upon the seizure of the interned German and Austrian vessels located in the port of New York, when war was declared, steps were taken by the Shipping Board to proceed with the repair of these vessels as rapidly as possible. Electric welding was adopted as the most expeditious method of repairing the engine castings. All told, the principle of electric welding has been applied to 15 ships in the port of New York. Of these, all are in commission and will probably be shortly ready for service.

In order to successfully weld with the electric arc it is necessary to have complete control of the current. The arc must be directed along the line of fracture to be welded. Welding must be done slowly, the metal being laid on layer by layer, and each layer must be caulked and peened to knock or chip out the metal that has oxidized or hardened. Cast iron is not welded to cast iron direct. Special alloy-steel wire is used to supply the welding metal. In welding two cast-iron edges together a layer of steel is welded to each, and then these steel layers are welded to each other. It is difficult to weld two cast-iron parts together, but it is comparatively easy to weld a steel piece to a cast-iron piece. The advantage of electric welding is that the work can be done without preheating the parts and without removing the parts from the ship, provided the electric arc can be properly directed along the fracture.

It is notable that in all the work done by electric welding there has never been a failure, and this is particularly remarkable when it is considered that almost every conceivable kind of a patch was made and that the operations were on a more extensive scale than ever before attempted. The writer believes that this is the first work of its kind of any moment to be attempted in marine engineering, and that the scrapping of cast-iron parts of machinery is entirely unnecessary and will very soon be a thing of the past. In every case in which this method was used the repaired part was quite as strong as before the damage was done, and in most cases stronger.

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